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Utilization of Waste Tyre Rubber In Pavement Base And Sub-Base Layers

Guttikonda Venkateswara Reddy[1], M.Ashok[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- — The disposal of waste tyres has emerged as a significant environmental challenge due to their non-biodegradable nature, large volume generation, and associated fire and health hazards. In the context of sustainable infrastructure development, the utilization of waste tyre rubber in pavement base and sub-base layers presents a promising alternative for both waste management and performance enhancement of flexible pavements. This study investigates the feasibility, engineering behavior, and structural performance of pavement base and sub-base materials modified with waste tyre rubber in various forms such as shredded rubber, crumb rubber, and rubber chips. Laboratory experimental investigations were conducted to evaluate key geotechnical and mechanical properties including compaction characteristics, California Bearing Ratio (CBR), unconfined compressive strength (UCS), resilient modulus, permeability, and durability. The influence of rubber content on density, stiffness, deformation characteristics, and energy absorption capacity was systematically analyzed. Results indicate that controlled incorporation of waste tyre rubber improves ductility, fatigue resistance, and resistance to cracking while contributing to reduction in material brittleness. However, excessive rubber content leads to reduction in load-bearing capacity due to lower stiffness and density. The study identifies optimum rubber content ranges suitable for base and sub-base applications based on performance criteria. Environmental and economic benefits, including reduced landfill burden, conservation of natural aggregates, and lifecycle cost savings, are also discussed. The findings support the potential of waste tyre rubber as a sustainable geomaterial for pavement applications, contributing to circular economy principles and resilient road infrastructure.

Keywords:Waste tyre rubber, Pavement base, Sub-base layer, Crumb rubber, Sustainable pavements, CBR, Resilient modulus

I. INTRODUCTION

The rapid expansion of the global automobile industry has resulted in a substantial increase in the generation of waste tyres, making their disposal a serious environmental and engineering challenge. Tyres are manufactured using complex combinations of natural and synthetic rubber, steel, carbon black, and chemical additives, which provide durability and resistance to wear. However, these same properties render tyres non-biodegradable, leading to their accumulation in landfills and open dumping sites. It is estimated that millions of waste tyres are generated annually worldwide, and a significant portion remains untreated or improperly disposed of, particularly in developing countries.

Waste tyres pose multiple environmental hazards. Large tyre stockpiles occupy valuable land resources and create unsightly landscapes. More critically, they are highly flammable, and tyre fires are extremely difficult to extinguish due to the high calorific value of rubber. Such fires can burn for weeks or months, releasing toxic gases and particulate matter that contaminate air, soil, and groundwater. Additionally, tyre dumps provide breeding grounds for mosquitoes and rodents, contributing to the spread of vector-borne diseases. These concerns have led environmental agencies to classify waste tyres as a priority solid waste requiring sustainable management solutions.

Conventional disposal methods such as landfilling and incineration have proven inadequate. Landfilling consumes large volumes of space and does not eliminate long-term environmental risks, while incineration generates hazardous emissions unless costly pollution control measures are implemented. Recycling options such as retreading and rubber reclamation account for only a limited fraction of total waste tyre generation. Consequently, there is a pressing need to identify large-scale, cost-effective, and environmentally sound applications for waste tyres.

II. MATERIALS AND METHODOLOGY

This chapter presents a detailed description of the materials employed, mix proportions adopted, and experimental procedures followed to evaluate the feasibility of incorporating waste tyre rubber in pavement base and sub-base layers. The selection of materials and testing methods was guided by the need to simulate practical pavement construction conditions while ensuring compliance with standard engineering practices. Emphasis was placed on the use of locally available materials to enhance the applicability of the research findings for real-world pavement projects.

III. EXPERIMENTAL SETUP

General

This chapter describes the experimental setup adopted for evaluating the engineering performance of rubber-modified pavement base and sub-base materials. Proper experimental setup is essential to ensure accuracy, repeatability, and reliability of laboratory test results. All specimens were prepared and tested under controlled laboratory conditions to simulate field behavior of pavement layers as closely as possible.

The experimental setup included specimen preparation facilities, compaction equipment, loading frames, deformation measuring instruments, and cyclic loading apparatus. Each component of the setup was selected in accordance with the requirements of the respective laboratory tests and relevant Indian Standards (IS), ASTM specifications, and IRC guidelines.

Specimen Preparation Setup

Specimens for compaction, CBR, UCS, permeability, and resilient modulus tests were prepared at their respective Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) values obtained from Standard Proctor compaction tests. The materials were mixed thoroughly in dry condition, followed by gradual addition of water to achieve uniform moisture distribution. Mixing was carried out manually or using mechanical mixers to prevent segregation of rubber particles.

Compaction was performed using standard moulds and rammers to achieve uniform density throughout the specimen. Care was taken to compact specimens in layers as specified in testing standards. After preparation, specimens were trimmed and checked for dimensional accuracy before testing.

Figure 4.1: Preparation of rubber-modified specimens at Optimum Moisture Content

Compaction and CBR Test Setup

The compaction setup consisted of a Standard Proctor compaction mould, rammer, and base plate assembly. For CBR testing, specimens were prepared in standard CBR moulds fitted with spacer discs and surcharge weights. After compaction, the specimens were placed in the CBR testing machine for load application.

For soaked CBR tests, specimens were submerged in water for the specified soaking period under controlled conditions. During testing, a penetration plunger was driven into the specimen at a constant rate, and load readings were recorded using a proving ring or load cell.

Figure 4.2: Standard Proctor compaction apparatus

UCS Test Setup
The Unconfined Compressive Strength (UCS) test setup consisted of a compression testing machine equipped with a loading frame and deformation measuring devices. Cylindrical specimens were placed centrally between the loading platens to ensure uniform load application. Axial load was applied at a controlled and constant rate as specified in the testing standards.

Deformation during loading was measured using dial gauges or electronic displacement transducers. The load and deformation data were recorded continuously until specimen failure. The UCS setup allowed accurate determination of stress–strain behavior, peak strength, and post-peak deformation characteristics.

Permeability Test Setup
The permeability test setup consisted of a constant head or falling head permeability apparatus suitable for granular materials. Specimens were placed inside the permeability mould and sealed properly to prevent leakage. Water was allowed to flow through the specimen under controlled head conditions, and the rate of flow was measured over a known time interval.

The setup ensured steady-state flow conditions for accurate determination of the coefficient of permeability. Rubber-modified specimens were tested carefully to avoid disturbance of internal structure during placement and testing.

Cyclic Loading and Resilient Modulus Test Setup
To evaluate the behavior of rubber-modified materials under repeated loading, a cyclic loading apparatus was used for resilient modulus testing. The setup included a servo-controlled loading frame capable of applying repeated axial loads simulating traffic loading conditions. Specimens were instrumented with deformation gauges to measure recoverable and permanent strains.

Cyclic loads were applied in predefined load cycles, and resilient modulus was calculated based on the elastic response of the specimen. This setup enabled assessment of deformation recovery, stiffness variation, and fatigue resistance of rubber-modified pavement layers.

Summary of Experimental Setup
The experimental setup adopted in this study ensured precise control over specimen preparation, loading conditions, and deformation measurements. Use of standardized equipment and testing procedures enabled reliable evaluation of compaction, strength, deformation, permeability, and resilient behavior of rubber-modified pavement materials. The data obtained from this experimental setup form the basis for detailed analysis and discussion presented in the subsequent chapter.

IV. RESULTS AND DISCUSSION

General
This chapter presents and discusses the results obtained from the laboratory experimental program conducted on rubber-modified pavement base and sub-base materials. The performance of the mixtures was evaluated in terms of compaction characteristics, California Bearing Ratio (CBR), unconfined compressive strength (UCS), deformation behavior, and permeability. The results of rubber-modified mixtures were compared with those of the control mix to assess the influence of waste tyre rubber content and rubber particle size on pavement performance.

Compaction Characteristics
Standard Proctor compaction test results were analyzed to evaluate the effect of waste tyre rubber on Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). The results indicated a consistent reduction in MDD with increasing rubber content for both crumb rubber and rubber chip mixtures.

This behavior is attributed to the lower specific gravity and elastic nature of rubber particles, which resist densification under compactive effort.

At the same time, OMC showed a marginal increase with increasing rubber content. The increase in moisture demand can be attributed to the higher energy required to compact rubber-modified mixtures and the increased void content introduced by rubber particles.

Table 5.1: Compaction Characteristics of Rubber-Modified Mixtures

Rubber Content (%)	**MDD (g/cc) – Control**	**MDD (g/cc) – Crumb Rubber**	**MDD (g/cc) – Rubber Chips**	**OMC (%)**
0	2.12	–	–	8.5
5	–	2.05	2.02	8.8
10	–	1.98	1.94	9.1
15	–	1.90	1.86	9.5
20	–	1.82	1.78	9.9

Discussion:
The reduction in MDD confirms the lightweight nature of rubber-modified materials, which can be advantageous in reducing stresses on weak subgrades. However, excessive reduction in density at higher rubber contents may adversely affect load-bearing capacity, emphasizing the need for optimum rubber content selection.

California Bearing Ratio (CBR) Results

CBR tests were conducted under both soaked and unsoaked conditions to assess load-bearing capacity and moisture susceptibility. The results showed that CBR values decreased marginally up to a certain rubber content and significantly thereafter. The initial marginal reduction is acceptable for pavement sub-base applications and is offset by improved deformation tolerance.

Table 5.2: Unsoaked CBR Results

Rubber Content (%)	**CBR (%) – Crumb Rubber**	**CBR (%) – Rubber Chips**
0	68	–
5	62	60
10	56	52
15	42	38
20	28	24

Table 5.3: Soaked CBR Results

Rubber Content (%)	**CBR (%) – Crumb Rubber**	**CBR (%) – Rubber Chips**
0	52	–
5	48	46
10	43	40
15	30	28
20	18	16

Discussion:
CBR values decreased gradually up to 10% rubber content and dropped significantly beyond this level. The reduction is primarily due to decreased stiffness and increased compressibility of rubber particles. However, up to 10% rubber content, CBR values remained within IRC limits for sub-base layers, indicating suitability for pavement applications.

Unconfined Compressive Strength (UCS) and Deformation Behavior

UCS test results indicated a decrease in peak compressive strength with increasing rubber content. However, rubber-modified specimens exhibited improved stress–strain behavior, characterized by higher strain at failure and gradual post-peak strength reduction.

Table 5.4: UCS Results and Strain at Failure

Rubber Content (%)	UCS (MPa)	Strain at Failure (%)
0	1.85	1.2
5	1.65	2.1
10	1.42	3.0
15	1.10	4.2
20	0.82	5.8

Discussion:
Although UCS values decreased with increasing rubber content, the strain at failure increased significantly. This indicates enhanced ductility and energy absorption capacity of rubber-modified mixtures. Such behavior is beneficial in pavement layers subjected to repeated traffic loading, as it reduces the likelihood of brittle failure and cracking.

5.5 Energy Absorption and Ductility Performance

Energy absorption was evaluated qualitatively from the area under stress–strain curves obtained from UCS testing. Rubber-modified specimens demonstrated larger areas under the curve, indicating superior energy dissipation capacity.

Table 5.5: Relative Energy Absorption Index

Rubber Content (%)	Energy Absorption Index
0	1.00
5	1.35
10	1.75
15	2.10
20	2.45

Discussion:
Improved energy absorption confirms that rubber-modified materials can effectively dissipate applied stresses, making them suitable for pavements exposed to heavy and cyclic loading. This improvement compensates for the reduction in strength at moderate rubber contents.

Permeability Results

Permeability test results showed a clear increase in the coefficient of permeability with increasing rubber content. Rubber chips exhibited higher permeability than crumb rubber due to larger particle size and increased void connectivity.

Table 5.6: Coefficient of Permeability

Rubber Content (%)	Permeability (cm/s) – Crumb Rubber	Permeability (cm/s) – Rubber Chips
0	2.1×10^{-3}	–
5	2.8×10^{-3}	3.2×10^{-3}
10	3.6×10^{-3}	4.1×10^{-3}
15	4.5×10^{-3}	5.2×10^{-3}
20	5.6×10^{-3}	6.4×10^{-3}

Discussion:
Enhanced permeability improves drainage characteristics of pavement sub-base layers, reducing moisture-related damage and improving long-term pavement durability.

Optimum Rubber Content

Based on combined evaluation of compaction, CBR, UCS, ductility, and permeability results, an optimum rubber content of 5–10% by weight of aggregates was identified. Within this range, acceptable strength is maintained while significant improvements in ductility, energy absorption, and drainage are achieved.

V. CONCLUSION & FUTURE SCOPE

Waste tyre rubber can be effectively utilized in pavement base and sub-base layers when incorporated at controlled and optimized percentages. The experimental results obtained in this study clearly demonstrate that partial replacement of conventional granular materials with waste tyre rubber modifies the mechanical and hydraulic behavior of pavement layers in a beneficial manner. By carefully selecting rubber content, it is possible to achieve a balance between strength, deformation resistance, and drainage performance, thereby making rubber-modified materials suitable for practical pavement applications.

An optimum rubber content plays a crucial role in enhancing the durability of pavement structures. At moderate rubber contents, the elastic nature of rubber particles improves deformation tolerance and energy absorption capacity of base and sub-base layers. This enhanced ductility reduces stress concentration and minimizes the risk of cracking and brittle failure under repeated traffic loading. As a result, rubber-modified pavement layers are better equipped to withstand cyclic loads and long-term service conditions, contributing to improved pavement performance and extended service life.

From a sustainability perspective, the utilization of waste tyre rubber in pavement construction offers significant environmental and economic benefits. Incorporating rubber into pavement layers reduces the volume of waste tyres disposed of in landfills, thereby mitigating environmental pollution and associated health hazards. At the same time, partial replacement of natural aggregates conserves non-renewable resources and reduces the demand for quarrying activities. These factors collectively support the development of environmentally responsible and resource-efficient pavement systems.

While the inclusion of waste tyre rubber leads to a reduction in certain strength parameters, such as maximum dry density and CBR at higher rubber contents, the study confirms that acceptable strength levels can be maintained within the identified optimum range. The marginal reduction in strength at moderate rubber contents is offset by significant improvements in ductility, energy dissipation, and moisture resistance. Therefore, rubber-modified materials can meet functional and structural requirements of pavement base and sub-base layers when properly designed.

In conclusion, the findings of this study establish that waste tyre rubber is a viable and sustainable alternative material for pavement base and sub-base applications. Adoption of rubber-modified pavement layers can lead to improved durability, reduced maintenance requirements, and enhanced environmental sustainability. With appropriate mix design, standardization, and field implementation, the use of waste tyre rubber has strong potential to contribute to the development of resilient and sustainable road infrastructure.

VI. FUTURE SCOPE

Future research should focus on evaluating the long-term field performance of rubber-modified pavement base and sub-base layers under actual traffic and environmental conditions. While laboratory studies provide valuable insights into material behavior, field performance data are essential for validating laboratory findings and assessing durability over extended service periods. Long-term monitoring of test sections, including measurements of rutting, cracking, settlement, and drainage performance, would help establish confidence in the use of waste tyre rubber for pavement construction.

Further studies should emphasize advanced numerical modeling and mechanistic analysis of rubber-modified pavement systems. Numerical models such as finite element or discrete element methods can be used to simulate stress–strain behavior, load distribution, and deformation characteristics under varying traffic loads. Such modeling approaches would enable better understanding of material behavior at different scales and support the development of performance-based pavement design frameworks tailored to rubber-modified materials.

Environmental impact assessment should form a key component of future research on waste tyre rubber utilization. Comprehensive studies examining potential leaching behavior, environmental compatibility, and life-cycle environmental impacts are necessary to ensure long-term sustainability. Life cycle assessment (LCA) and carbon footprint analysis can be used to quantify environmental benefits in terms of reduced emissions, resource conservation, and waste management efficiency.

Future investigations should also explore optimization of rubber content, particle size, and blending techniques to further enhance mechanical performance while maintaining adequate strength. The influence of different types of rubber processing methods and surface treatments on bonding and interaction with aggregates may provide additional performance improvements. Such studies would contribute to refining mix design guidelines for various pavement applications.

Finally, there is a need for the development of standardized design guidelines and specifications for the use of waste tyre rubber in pavement base and sub-base layers. Collaboration between researchers, industry professionals, and road authorities can facilitate the translation of research outcomes into practical standards. Establishing clear guidelines supported by field validation will promote wider adoption of rubber-modified pavement technologies in sustainable road infrastructure development.

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