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Analysis and Design of using Waste Rubber Tyres in Construction of Bituminous Road

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Abstract - The increasing usage of vehicles, including four-wheeled, two-wheeled, and others, has led to a corresponding rise in the disposal of used tires. In India, discarded tires are classified as hazardous or solid waste. It is estimated that approximately 60% of these tires are disposed of through unknown channels in both urban and rural areas. This improper disposal poses numerous environmental challenges, including air pollution from open burning of tires, which can release hazardous pollutants such as dioxins, polycyclic aromatic hydrocarbons, and nitrogen oxides, as well as visual pollution.

To address these issues, it is crucial to effectively utilize waste materials as technology advances in various fields. One potential solution is to process old tires into rubber aggregates, which can then be utilized as properly sized aggregates in various bituminous mixtures. This approach not only reduces reliance on finite traditional aggregates but also helps mitigate pollution stemming from discarded tires.

The construction materials sector has been actively exploring ways to repurpose waste materials, such as worn-out tires, into functional and cost-effective commodities. The disposal of rubber waste from tires remains a significant environmental concern globally.

***Key Words*:** Tyre, Dioxin, Rubber

1. INTRODUCTION

The introduction of rubber aggregate addresses issues related to heat cracking and persistent deformation in road construction. Rubber aggregate can serve multiple purposes, including chip seal coating, joint filling, crack sealing, and as an ingredient in special asphalt paving materials designed to combat thermal cracking and permanent deformation, particularly in hot climates. Additionally, rubber's sound-absorbing properties contribute to its role in reducing noise pollution, thereby enhancing the functionality and condition of roadways.
The disposal of various industrial wastes poses a significant challenge due to their non-biodegradable nature, leading to environmental contamination. The construction of roads traditionally relies on natural resources such as dirt, stone aggregate, sand, bitumen, and cement, which are finite and becoming increasingly expensive to obtain. In response to this concern, scientists are exploring alternative materials for road construction to alleviate pollution and disposal issues. The utilization of waste tires in road construction offers a promising solution, potentially yielding significant financial returns.

To maximize the efficient use of solid waste in road construction, it is essential to establish relevant requirements and standards for incorporating these materials into various layers of the road surface. The development of low-traffic roads using waste tire materials can offer two key advantages: the removal of large waste dumps from valuable land and the preservation of natural aggregate reserves, thereby contributing to environmental conservation.

While rubber tires are user-friendly, they are not environmentally friendly due to their non-biodegradable nature. The practice of open burning and landfill dumping of old tires is becoming increasingly unsustainable as landfill space diminishes and environmental degradation worsens. By incorporating recycled rubber into bitumen, the performance of asphalt pavements can be improved, leading to more cost-effective, quieter roads that also benefit the environment. Studies have shown that the addition of crumb rubber modified bitumen (CRMB 55) enhances the properties of bitumen compared to conventional bitumen (60/70), even at lower modified binder levels. By implementing Marshall mix design and varying the modified bitumen content while maintaining the optimal rubber content, significant improvements in bitumen properties can be achieved, resulting in enhanced pavement performance and environmental sustainability.

Fig-1: Rubber Specimen of tyre

PROPERTIES OF RUBBER TYRES

Old tires possess several qualities that make them ideal for use in roadway construction:

1. Durable: Tires are designed to withstand significant wear and tear, making them durable materials for road construction. This durability translates to longevity and resilience in the road surface.
2. Flexible: The rubber composition of tires provides flexibility, allowing them to adapt to various road conditions, including changes in temperature and traffic loads. This flexibility helps prevent cracking and rutting in the road surface.
3. Sound Absorption: Rubber has natural sound-absorbing properties, which can help reduce noise pollution on roadways.

Incorporating rubber from old tires into road construction can contribute to quieter road surfaces, especially in urban areas.

4. Elasticity: Rubber is inherently elastic, meaning it can deform under stress and return to its original shape once the stress is removed. This elasticity helps improve the resilience and durability of road surfaces, particularly in areas with heavy traffic or extreme weather conditions.

5. Non-biodegradable: While this may not be an ideal quality from an environmental standpoint, the non-biodegradable nature of tires means they have a long lifespan and can withstand exposure to the elements without degrading quickly. This makes them suitable for long-lasting road construction applications.

6. Cost-effective: Recycling old tires for use in roadway construction can be a cost-effective alternative to traditional construction materials. It reduces the need for virgin materials and can lower construction costs, making it an attractive option for budget-conscious projects.

7. Environmentally Sustainable: Repurposing old tires for road construction helps divert them from landfills, reducing waste and environmental pollution. It also conserves natural resources by decreasing the demand for virgin materials, contributing to overall environmental sustainability.

NEED FOR RUBBERIZED BITUMEN

The need for rubberized bitumen in roadway construction is driven by several factors:

1. Hostile Traffic Conditions: With increasing traffic volume and heavier vehicles on roads, traditional bituminous mixtures may struggle to withstand the demands of a more hostile traffic situation. Rubberized bitumen offers greater flexibility and fatigue resistance, enhancing the durability of road surfaces under heavy traffic loads.

2. Extreme Weather Conditions: Daily and seasonal temperature fluctuations can cause traditional asphalt to crack and deteriorate over time. Rubberized bitumen provides increased flexibility, allowing road surfaces to expand and contract without cracking, thus better withstanding extreme weather conditions.

3. Maintenance Requirements: Maintaining roads in good serviceable condition is essential for safety and usability. Rubberized bitumen helps improve the longevity of road surfaces by providing greater flexibility and resistance to fatigue, reducing the frequency of maintenance and repair work.

4. Flexibility and Fatigue Resistance: Rubberized bitumen enhances the flexibility and fatigue resistance of bituminous mixtures, making them better able to withstand repeated loading from heavy traffic and extreme weather conditions without developing cracks or deformations.

5. Cohesiveness and Weather Resistance: The increased cohesiveness of rubberized bitumen helps improve weather resistance and adherence to the road surface. This reduces the risk of the binder being washed away by water, leading to longer-lasting road surfaces.

6. Rigidity Modulus: Rubberized bitumen can achieve a greater rigidity modulus compared to traditional asphalt. This allows for the reduction of resurfacing thickness in urban areas, minimizing milling requirements and prolonging the life of the road surface.

7. Protection Against Failure: Rubberized bitumen provides enhanced protection against creep failure, ravelling, cracking, and deformation, ensuring the integrity and longevity of road surfaces even under challenging conditions.

In summary, rubberized bitumen addresses the need for durable, weather-resistant, and low-maintenance road surfaces, making it an essential material for modern roadway construction, especially in areas facing hostile traffic conditions and extreme weather.

SCOPE OF THE PRESENT STUDY

1. Construction of flexible pavement using used rubber tyres.
2. To minimise the use of natural resources in theproduction of the pavement.
3. To investigate the variance in strength characteristics through various testing.
4. To understand the standard of pavement rubber replacement.
5. To keep building costs as low as possible.
6. The burning of these discarded tyres produces carbon.
7. Due to the land issues in our nation, this quantity of tyres is so great that it is hazardous and unpleasant to place.
8. It was discovered that dangerous compounds had been in contact with very acidic solutions.

2. METHODOLOGY

Waste rubber tires were collected from various sources such as landfills, waste buyers, and roadside locations. These tires were then sorted according to size requirements for use as aggregate in bituminous mixtures. Using a tire cutting device (depicted in Fig. 3.1), the discarded tires were chopped into aggregate with diameters ranging from 22.4 mm to 6.00 mm, as per IRC-SP20 standards.

The waste rubber tires can be processed into various forms, including whole, split, ground, chopped, or shredded tires, as well as crumb rubber products. To prepare the rubber for use in bituminous mixtures, it undergoes magnetic separation twice, followed by screening to recover rubber in a range of sizes, resulting in what is known as rubber aggregate. If required, the rubber aggregate is further cleaned through washing or dust removal processes.

According to the mix design specifications, the rubber aggregate is sieved to retain particles larger than 22.4 mm and pass through a 5.6 mm sieve. It is then added to the bituminous mix at a rate of 10 to 20 percent by weight of the stone aggregate. The rubber aggregates are mixed with stone aggregate and bitumen at temperatures between 160°C to 170°C to ensure proper blending of the bituminous mix.

As waste rubber tires are thermodynamically stable, they do not melt in bitumen during the mixing process in the hot mix plant. This ensures that the rubber aggregate maintains its integrity and properties within the bituminous mix, contributing to the desired performance characteristics of the final pavement material.

. **Fig:2** Rubber tyres cutting machine

Ambient grinding- This processing method involves grinding or processing used tires at temperatures equal to or higher than ambient temperature. Ambient processing is often necessary to produce irregularly shaped, torn particles with relatively wide surface areas, enhancing their contact with paving bitumen. The critical stage in this mechanical grinding process, which is accomplished using revolving knives and blades, is the separation of fibers, including steel fibers, if present. Once the metallic components are removed, ambient grinding can produce rubber crumbs with a grain size ranging from 5 to 0.5 mm. Ambient grinding is widely considered the most popular and possibly the most economical method for treating end-of-life tires. Figure 3 provides a schematic illustration of ambient grinding.

Fig.3. Schematic representation of ambient grindinG

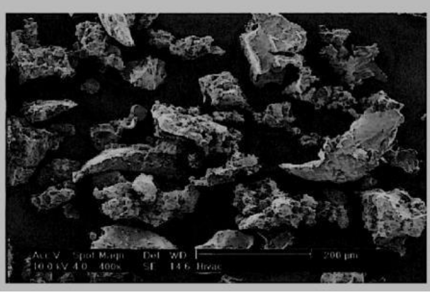
Cryogenic grinding- The process involves freezing the rubber tire rubber (RTR) using liquid nitrogen, typically at temperatures between 87 and 198 °C, until it becomes brittle, as illustrated in Fig 4. Once frozen, the rubber is broken into smooth particles with a relatively lower surface area compared to those produced by ambient grinding methods.

Research by Oliver has shown how the specific gravity and particle size of the rubber granulate, as well as the surface porosity of the granules, affect the elastic properties of the crumb rubber and its performance in the final mix. Contrary to results obtained using granules with larger porous surfaces and lower specific weight, rubber particles with a smooth surface in the wet process have shown to exhibit less reactivity with bitumen and poorer elastic characteristics in the mixture.

As a result, it is not advisable to use crumb rubber derived from the cryogenic process in bituminous mixes. The table below summarizes a comparison of the characteristics of cryogenic and ambient ground rubber.

Fig.4 and Table: Cryogenic rubber crumbs. SEM analysisat 200um and 400x magnification

Physical property	Ambient	Cryogenic
Specific gravity	Same	Same
Particle shape	Irregular	Regular
Fibre content	0.5%	Nil
Steel content	0.1%	Nil
Cost	Comparable	Comparable



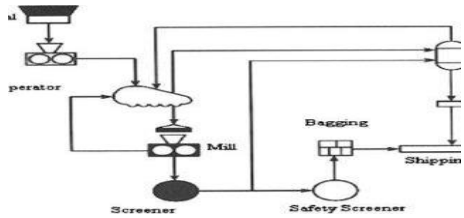
Wet-grinding- The wet-grinding technique, a proprietary method, utilizes a liquid media, typically water, to further reduce the size of microscopic rubber particles. Grinding occurs between two closely spaced grinding wheels. The resulting fine mesh rubber tire rubber (RTR) is commonly utilized as a bitumen modifier.

In this process, high-pressure water is used to reduce the size of RTR into smaller particles. Water jets, operating at very high speeds in arrays under intense pressure (approximately 55,000 psi), break down the RTR, producing clean and wire-free rubber crumbs.

While the methodology for this process is relatively new and not widely known in the industry due to its recent development, the resulting rubber crumbs exhibit a high level of roughness, making them highly sought-after for bitumen modification.

3. EXPERIMENTAL STUDIES

Mixing Of Crumb Rubber with Plain Bitumen- A metal container with a 1.5-liter capacity was filled with 500 g of bitumen and heated until it reached a fluid state to prepare the



modified binders. Crumb rubber was added to the heated bitumen once it reached a temperature of 160 °C in preparation for mixing. Each mixed sample contained varying percentages of crumb rubber, ranging from 0% to 14% by weight.

The mixing process involved hand blending the mixture for 3–4 minutes, ensuring thorough incorporation of the crumb rubber. The mixture was then heated to a temperature between 160 °C and 170 °C and stirred continuously for approximately 50 minutes using a mechanical stirrer. Care was taken to maintain the temperature within the specified range throughout the stirring process.

After stirring for approximately 55 minutes, the modified bitumen was allowed to cool to room temperature before being properly stored for testing. This ensured that the modified binders were prepared under controlled conditions and ready for evaluation.

Physical Properties of rubber tyres-

Sr No.	Properties of Crumb rubber	Result
1	Specific gravity	1.016
2	Moisture content	0.70%

Penetration test-

The hardness or softness of bitumen, standardized by the Bureau of Indian Standards (BIS), can be determined using a penetrometer. This device measures the depth, in tenths of a millimeter, to which a standard loaded needle penetrates vertically into the bitumen sample in 5 seconds.

The penetrometer consists of a 100g needle assembly and a locking and unlocking mechanism that can be used in any position. To conduct the test, the bitumen is thoroughly agitated until it reaches a pouring consistency. It is then poured into containers at a depth that is at least 15 mm deeper than the anticipated penetration depth.

The test is conducted at a specific temperature of 25°C, as any variation in temperature can significantly affect the penetration value. The size of the needle, the weight on the needle, and the test temperature all play crucial roles in obtaining accurate penetration values.

For example, when bitumen is graded as 40/50, it means that under typical test conditions, the penetration value falls between 40 and 50. In warmer areas, it is preferable to use a lower penetration grade of bitumen. This grading system helps ensure that bitumen is selected appropriately based on its intended application and the prevailing environmental conditions.

Record of Observation for penetration test:

Actual temperature = 25˚ c

% Of CRMB	Reading	Trial 1	Trial 2	Trial 3	Average. Value In mm
0% of CRMB	Initial	0	0	0	69.00
	Final	65	68	75	
Penetration Value		**65**	**68**	**75**	
8% of CRMB	Initial	0	0	0	49.33
	Final	45	46	53	
Penetration Value		**45**	**46**	**53**	
10% of CRMB	Initial	0	0	0	38.67
	Final	34	35	45	
Penetration Value		**34**	**35**	**45**	
12% of CRMB	Initial	0	0	0	19.67
	Final	19	21	19	
Penetration Value		**19**	**21**	**19**	
14% of CRMB	Initial	0	0	0	14.33
	Final	14	15	14	
Penetration Value		**14**	**15**	**14**	
% Of CRMB	**Reading**	**Trial 1**	**Trial 2**	**Trial 3**	**Average. Value In mm**
	Final	14	15	14	
Penetration Value		**14**	**15**	**14**	

Used rubber tires can be processed in various ways, including as whole tires, sliced tires, chopped tires, ground rubber, and products made from crumb rubber. When rubber particles intended for use in bituminous mixtures undergo a dual cycle of magnetic separation, they are then screened and recovered in various sizes, resulting in the formation of a material known as "Rubber Aggregate."

To prepare the used rubber tires for further processing, they undergo cleaning procedures, including washing and de-dusting. Following mix design parameters, all rubber bits are sieved through a 22.4 mm sieve and retained via a 5.6 mm sieve. These rubber bits, accounting for 10–20% by weight of the bituminous mix, are thoroughly mixed with stone aggregate and bitumen at temperatures ranging between 160°C and 170°C. The well-sieved and cleaned rubber aggregate is then added to the mixture.

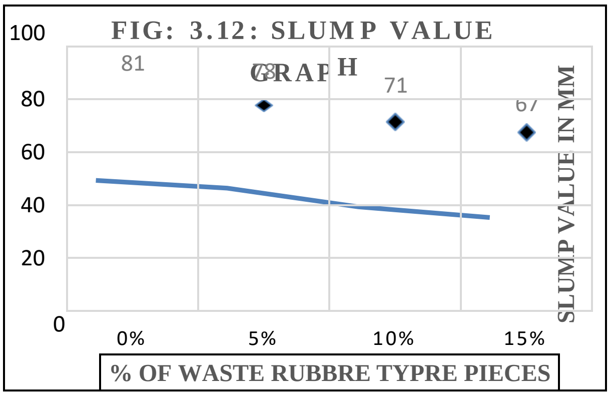
Since waste rubber tires are thermodynamically stable, they do not melt when mixed with bitumen in a mixing plant. These discarded tires are collected in large quantities from roadside ditches, landfills, and waste buyers. Upon collection, the waste tires are sized according to the requirements for mixing.

The tire cutting machine depicted in the image below cuts the discarded tires into aggregate sizes, typically ranging from 22.4 mm to 6.00 mm, as per IRC:SP20 standards.**Testing of Specimen-**

The specimens were taken out of the mould after 24 hours and placed in water for 7 and 28 days to cure. The specimens' compressive and flexural strengths were evaluated after curing. The strength of the specimens was evaluated at 7 days and 28 days using a compression testing machine with a 2000 KN capacity in line with the requirements of the Indian Standard standard IS:516- 1959. The commonly used empirical test, known as the slump test with a w/c ratio of 0.40 for addition of varying percentages of waste tyre rubber, is used to determine the workability of concrete of the M30 grade. Values obtained for various percentage mixes are displayed in the following table-

Table -1: Slump values for different percentage of mix

% of Waste Tyre Rubber	Slump value (mm)
0%	81mm
5%	78mm
10%	71mm
15%	67mm



Compressive Strength Test- The compression strength results obtained after 28 days indicate that the compressive strength improves as the proportion of waste tire rubber increases, up to 15%. However, beyond this point, there is a decline in compressive strength. In other words, waste tire rubber can effectively replace up to 15% of the natural coarse aggregate. According to recent research, waste tire rubber can substitute coarse gravel by up to 10%.

Specifically, when 5% of the coarse aggregate is replaced with waste tire rubber, the compressive strength increases by 3.12%. However, when 15% of the coarse aggregate is replaced with waste tire rubber, the strength decreases by 19.32%, maintaining a water-to-cement ratio (W/C) of 0.40.

4. MATERIAL MIX DESIGN & RESULTS

DISCUSSIONS

Mix Design-

This chapter provides an overview of the components of crumb rubber modified bitumen (CRM) and their respective requirements. It delves into the manufacturing process and qualities of CRM, as well as aspects related to its shipment and management. Additionally, the chapter discusses the characteristics of asphalt cement in the context of asphalt rubber.

Material Required-

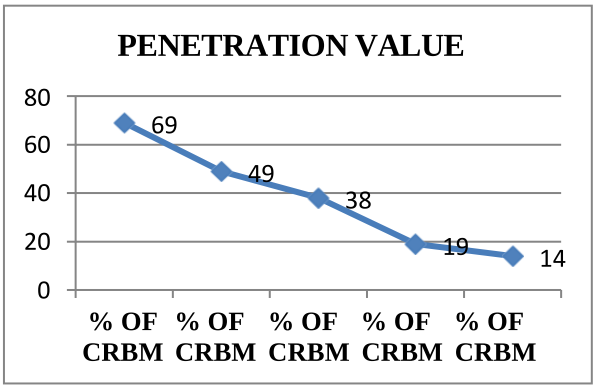
1. Bitumen
2. Crumb Rubber
3. Cracker Mill
4. Granulator
5. Wet grinding
6. Cryogenic Process

EXPERIMENTAL RESULTS-

Penetration-

Tests were conducted on both standard bitumen and modified bitumen, which contained varying percentages of rubber waste (0%, 8%, 10%, 12%, and 14%). The results of these tests are presented in Table 2.

According to the findings of the test, the typical bitumen had a penetration value of 69 mm. As the percentage of rubber waste added increased, the penetration value decreased. A lower penetration value indicates a stronger grade of asphalt, which enhances road durability and reduces susceptibility to water damage.



Softening Point Test-

The term "softening point" refers to the temperature at which bitumen softens to a specified degree, as per test requirements. This test is typically conducted using the Ring and Ball apparatus. In this test, a brass ring containing a sample of bitumen is suspended in a liquid medium, such as water or glycerin, at a specific temperature. The liquid is heated at a rate of 5°C per minute, while a steel ball is placed on top of the bitumen sample. The temperature at which the softened bitumen reaches a metal plate located below, at a specific distance, is recorded.

Higher softening points are often preferred in hot environments because they indicate reduced susceptibility to temperature-induced softening.

	% Of CRMB	Reading 1 in Degree	Reading 2 in degree	Mean value in Degree
Temperature at which bitumen softens and touches the bottom plate by sinking of ball	0%ofCRMB	42.4	43.1	42.75
	8%OfCRMB	49.1	51.5	50.3
	10%OfCRMB	51.4	51.9	51.65
	12%OfCRMB	54.1	54.9	54.5
	14%OfCRMB	54.2	55.8	55

Table 2-Softening point test resultResult

Normal bitumen and modified bitumen containing rubber waste contents of 0%, 8%, 10%, 12%, and 14% underwent softening point tests, and the results are presented in Table 4.1. According to the test findings, typical bitumen had a softening point of 42.75 degrees Celsius.

As the amount of rubber waste added increased, the softening point also increased. This indicates that as the amount of rubber waste increased, the bitumen became less sensitive to temperature variations.

5. CONCLUSION

The utilization of discarded plastic and rubber tires in road construction yields superior results due to the improved adherence between bitumen and these materials. This enhanced bonding and increased contact area between polymers and bitumen reduce the occurrence of voids, ultimately decreasing bitumen degradation and moisture absorption due to trapped air. Consequently, roads become more durable and capable of withstanding heavy traffic. Additionally, incorporating rubber aggregate into bituminous mixtures reduces the volume of traditional stone aggregate used, thereby conserving finite resources and mitigating pollution from discarded tires.

It is advocated that the road paving industry widely adopt RTR-MBs (Rubber Tire Rubber-Modified Bitumen) technology due to its numerous advantages in enhancing the performance of asphalt pavements and overall infrastructure sustainability. Therefore, exploring RTR-MBs technologies as a primary alternative to current binders used in road paving is highly encouraged.

Key points highlighted in the text include:

- Waste tires added as rubber aggregate alter the flexibility of the top layer of roads.
- The optimal composition of old waste rubber tires falls within the range of 5% to 20%.
- Thermal cracking and persistent deformation are less prevalent in warmer temperature regions.
- Rubber possesses sound absorption properties, contributing to

the reduction of noise pollution on busy highways.
- Incorporating waste rubber tires enhances road performance and quality over time.
- A portion of conventional stone aggregate can be salvaged.
- The results of the penetration value test indicate a decrease in penetration value as more rubber waste is added. A lower penetration value results in a stronger grade of asphalt, increasing road strength and minimizing water damage.
- The softening point test demonstrates an increase in softening point with the addition of more rubber waste, indicating improved resistance to temperature variations. Increased softening point provides protection from hot weather conditions.
- According to the results of the ductility test, adding rubber waste causes the bitumen to harden.

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