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PERFORMANCE ASSESSMENT OF GTR MODIFIED ASPHALT CONCRETE: A COMPREHENSIVE STUDY ON MECHANICAL AND DURABILITY PROPERTIES

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ABSTRACT

The rising number of vehicles on the road has led to a drastic increase in tire disposal, which makes discarded tires a prominent environmental issue. In response, the bituminous pavements modified with Ground Tire Rubber (GTR) present an effective solution to improve mechanical and durability properties of asphalt binders while a reduction of the environmental impact of waste tires is achieved. This study examines the effect of Ground Tire Rubber (GTR) modification on the rutting resistance, fracture resistance and moisture susceptibility of asphalt mixtures using two performance grades: PG 64-22 and PG 76-22 binder. For this study, GTR was added at different percentages from 0-20% for PG 64-22 and 0-8% for PG-76-22 by binder weight to satisfy field usage conditions. Rutting resistance was measured by the Hamburg Wheel Tracking Test (HWTT). In addition, fracture resistance and moisture susceptibility of asphalt mixture was evaluated through Semi-Circular Bend (SCB) test and Tensile Strength Ratio (TSR) test, respectively, to assess the long-term performance and durability of modified binders. The results showed that for rutting resistance, PG 64-22 binder with 15% GTR showed a notable reduction of rut depth by 28.7%, but increasing the GTR content to 20% resulted in an increase of the rut depth due to compaction issues and phase separation. In contrast, PG 76-22 showed optimal performance when the GTR content was 5% leading to 43.9% decrease in rut depth, but high GTR content (8%) showed increased rut depth possibly due to excessive stiffness which interferes with the elastic recovery. For fracture resistance, the addition of GTR resulted in better fracture energy, especially at the lower contents of 5% to 10%, and the fracture energy of PG 76-22 was higher than that of PG 64-22. However, both binders showed increased stiffness with the GTR with PG 64-22 showing consistent improvement while PG 76-22 had optimum stiffness at 5% GTR but decreased at higher contents. In addition, the Tensile Strength Ratio (TSR) was stable for PG 64-22, suggesting that the addition of GTR did not make a significant difference of tensile strength, whereas PG 76-22 had a minor decrease at 8% GTR. Overall, the results confirm the use of GTR modified binders in asphalt pavement applications, providing balance between the mechanical performance and the environment.

Keywords: *Ground Tire Rubber (GTR), Rutting, Fracture, Moisture Susceptibility, Performance Grade.*

1. INTRODUCTION

The Ground Tire Rubber is made from scrap tires and mixed with asphalt binder that enhances elasticity and physical properties as well as asphalt pavement performance (George et al., 2011). The recycling methods such as the utilization of ground tire rubber (GTR) in its multiple applications like asphalt pavements are important in lessening the negative effects of scrap tires disposal to the environment and in enhancing the concept of the circular economy. In the present time, 12 million scrap tires are converted into ground tire rubber to modify its use in asphalt binder construction each year (Willis et al., 2013). There is always a belief that crumb rubber would be a perfect substitute polymer material to enhance the performance properties of the hot mix asphalt (Mashaan et al., 2014). Ground rubber tires, produced through grinding and shearing processes where scrap tires are mechanically broken down into smaller particles, ultimately enhance road performance and provide better cushioning (Shatnawi, 2001). Waste tires disposal has emerged as a big environmental concern. One of the possible solutions is to convert discarded tires into crumb rubber (CR), which can be used as an additive to asphalt mixtures or as a modifier to asphalt binders, contributing to the solution of the problem of waste management and performance of roads. Studies have indicated that crumb rubber-modified asphalt and mixtures due to their energy efficiency and environmental sustainability provide a great gain in form of increased resistance to fatigue cracking, better performance in extreme temperatures, and the capacity to reduce noise (Lo Presti, 2013). In recent years, modification of asphalt by recycled materials has increasingly been adopted to minimize environmental impact through minimization of waste by using recycled plastic, crumb rubber, fly ash, resin, and biopolymer (Rangaraj & Mukesh, 2020). These reusable substances significantly improve viscoelastic characteristics of the asphalt binder like complex shear modulus, and phase angle (Wang et al., 2020). Modifying asphalt binders with polymers (e.g., plastic, rubber, or polythene) also enhances their ability to resist deformation caused by Moisture susceptibility (Alghrafy et al., 2021). One of the most common polymer materials frequently used in asphalt binder modification is crumb rubber or ground tire rubber. It exhibits improved resistance to rutting, aging, and fatigue cracking than virgin binder (Shu & Huang, 2014). Moreover, Hot Mix Asphalt combined with ground tire rubber is stronger in permanent deformation resistance, high stiffness and reaches efficiency in high-temperature situations (Riyad et al., 2024). In addition, crumb rubber modification enhances fatigue behavior with all particle sizes and types; larger particles tend to provide better fatigue life (Xiao et al., 2009). In another study, it has been found that GTR modification of PG 64-22 and PG 76-22 binders leads to lower creep stiffness and higher m-values, resulting in improved flexibility and low-temperature performance (Islam et al., 2025). Furthermore, the incorporation of Ground Tire Rubber (GTR) improves the dynamic modulus resistance of asphalt mixtures and contributes to extended pavement service life when used with appropriate binder types (Islam, 2025). This study aims to investigate, the effects of Ground Tire Rubber (GTR) on the mechanical and durability performance of asphalt binders (PG 64-22 and PG 76-22), with the emphasis on rutting resistance, fracture resistance, tensile strength, and moisture susceptibility.

2. METHODOLOGY

2.1. Materials

Two types of asphalt binder were used in the study, namely PG 64-22 and 76-22, where PG 64-22 was unmodified and PG 76-22 was modified with Styrene Butadiene Styrene (SBS) polymer. Ground tire rubber (GTR) was taken as a primary modifier to improve binder fatigue performance (Fig.1b). The GTR particles, which were a mixture of vulcanized rubber, carbon black, fibers, and trace inorganic substances, were filtered on a Mesh-30 screen (<600 μm). The samples of the asphalt concrete were made with aggregates such as #7 (coarse) and #89 (fine), and MS-10, mineral fillers, and lime (Fig.1c). Both asphalt binders used in this study were provided by the Reeves Construction Company, situated near Statesboro, Georgia (Fig.1a). The aggregates used in the study were characterized by their gradation, as shown in Table 1, which provides the details of the open- graded friction course (OGFC) material with a nominal size of 12.5 mm. The gradation distribution is further illustrated in Figure 2, where the graphical representation of the OGFC gradation is provided to show the particle size distribution.

Figure 1. Materials used in the study: (a) Asphalt binders, (b) Ground Tire Rubber, and (c) Aggregates

Table 1. Gradation of open graded friction course material (12.5 mm)

Sieve Size	Aggregate Type						
	#7	#89	MS-10	Mineral Filler	Lime	(%) of Passing	Specification
% of Mixture	57	31	7	4	1	100	
3/4 inch	100	100	100	100	100	100	100
1/2 inch	86.5	100	100	100	100	92.3	85-100
3/8 inch	46.7	64	100	100	100	71.9	55-75
No. 4	3.07	7.4	97.8	99.7	100	16.1	15-25
No. 8	0.58	1.5	20.5	74.7	100	6.6	5--10
No.200	0	0.3	17	20.8	100	3.2	2--4

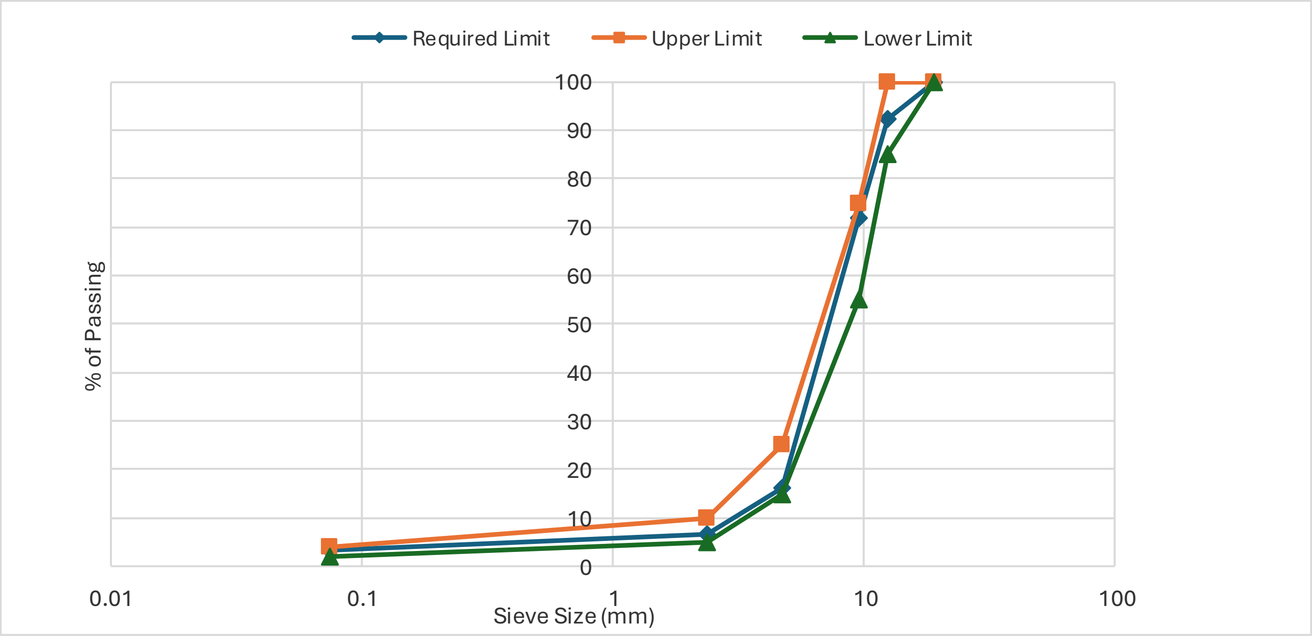


Figure 2: Particle size distribution of Open Graded Friction Coarse

2.2. Sample Preparation

Initially, the base binder PG 64-22 and PG 76-22 were heated to 160 degrees Celsius along with Aggregate #7, #89, MS-10, mineral fillers, and lime to ensure uniform coating and workability. Subsequently, a mixer machine blended these components with 0%, 5%, 10%, 15% and 20% GTR for PG 64-22, and 0%, 3%, 5%, and 8% GTR for PG 76-22 (Fig. 3a and b). The GTR contents were selected based on binder stiffness and practical workability limits. A wider range (0–20% at 5% intervals) was used for the PG 64-22 binder to capture performance trends and identify an upper practical limit, whereas lower GTR contents (0–8%) were selected for the stiffer PG 76-22 binder to avoid excessive viscosity and constructability issues, as indicated by previous studies and industry practices. Unmodified binders (0% GTR) were included as controls. After mixing, the asphalt aggregate mixture was aged in an oven at the same temperature for two hours. Finally, samples were prepared using a gyratory compactor for further analysis (Fig. 3c).

Figure 3: Sample preparation: (a) Mixture machine, (b) Mixed aggregates and (c) Sample through gyratory

2.3. Humburg Wheel Tracking Test (HWTT)

The Hamburg Wheel Tracking Test (HWTT), conducted according to AASHTO T324, was used to evaluate the rutting resistance and moisture susceptibility of asphalt mixtures containing varying percentages of Ground Tire Rubber (GTR). This test involves repeatedly rolling a steel wheel over a submerged asphalt specimen at an elevated temperature, simulating combined effects of traffic loading, heat, and water (Fig. 4). The HWTT specimens were prepared by slicing 150-mm-diameter cylindrical asphalt samples with a typical thickness of 50 mm. The test was performed at a temperature of 50°C using a 705 N (158 lbs) steel wheel load, with a maximum of 20,000 passes or until a rut depth of 20 mm was reached. However, many highway agencies commonly recommend a maximum rut depth of approximately 12.5 mm at 20,000 passes as an acceptance limit to indicate adequate rutting resistance of asphalt mixtures. The number of passes and the depth of the rut was observed continuously and the final rut depth was taken to measure the performance of each mixture. The test also proved to be an excellent simulation of the field conditions due to the integration of the load, temperature and moisture on the test and three replicates were done using each type of mixture to ensure accuracy and reliability in the results.

Figure 4: Sample (a) under testing condition and (b) after testing

2.4. Semi-Circular Bend (SCB) Test

The fracture resistance of asphalt mixtures at various percentages of Ground Tire Rubber (GTR) was determined by the Semi-Circular Bend (SCB) test, which is conducted according to the ASTM D8044. Two SCB test variants were considered: (a) Illinois SCB and (b) Louisiana SCB. The Illinois SCB test follows guidelines from the Illinois Center for Transportation (ICT) and meets ASTM D8044 standards. A notch depth of 15 mm and a loading rate of 50 mm/min were used. The Louisiana SCB test follows procedures set by the Louisiana Transportation Research Center (LTRC), which also follows ASTM standards. For the SCB-Louisiana configuration, a notch depth of 25 mm and a lower loading rate of 0.5 mm/min were utilized. A total of 32 SCB samples were prepared and tested under controlled temperature conditions to evaluate the effect of ground tire rubber (GTR) on fracture energy and stiffness, with 16 specimens assigned to each SCB test configuration. The SCB specimens were prepared by halving 150-mm-diameter cylindrical asphalt samples with a typical thickness of 50 mm. All specimens were at monotonic loading until failure and load displacement data were tabulated to determine important parameters that included maximum load, displacement at fracture and fracture energy (J/m^2). The lower fracture energy on SCB-LA specimens compared to the shallower SCB-IL specimens was due to deeper notch in the specimen, emphasizing the geometry sensitive nature of fracture behavior. This test gave a credible picture of the tensile stress cracking capabilities, and flexibility of the GTR-modified asphalt mixtures as shown in Fig.5.

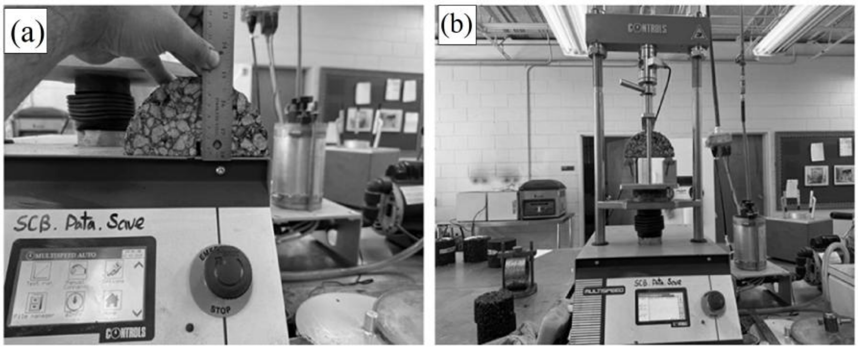


Figure 5: (a) Notch dimension and (b) Sample under Loading condition

2.5. Tensile Strength Ratio (TSR) Test

Tensile Strength Ratio (TSR) Test was performed according to AASHTO T 283. It was conducted to determine the effect of moisture of asphalt mixtures having varying percentages of Ground Tire Rubber (GTR). Asphalt specimens were prepared using the Marshall compaction technique into cylindrical samples with a diameter of 101.6 mm and a height of 63.5 ± 2.5 mm, in accordance with AASHTO T 283 and grouped into two categories: conditioned (wet) and unconditioned (dry). The conditioned specimens were first saturated with a vacuum chamber to 70–80% of the maximum absorption of water and then subjected to 24 hours of moisture inside a 60°C water bath to mimic long-term exposure and the unconditioned specimens were left at room temperature. The samples of both sets were then equilibrated at 25°C after conditioning and put under indirect tensile loads until failure (Fig.6). The maximum load at failure (P), thickness of the specimen (t) and diameter (D) was used to compute the Indirect Tensile Strength (ITS) as indicated in the Eq. (1):

$$ITS = \frac{2P}{\pi D t} \tag{1}$$

The Tensile Strength Ratio (TSR) was subsequently calculated as the ratio of the average tensile strength of conditioned samples to that of unconditioned samples in terms of a percentage as in Eq. (2):

$$TSR = \frac{Average\ ITS\ of\ Conditioned\ samples}{Average\ ITS\ of\ Subset\ B\ Unconditioned} \text{x}100 \qquad (2)$$

This value offered quantitative data about the mixture resistance to the damage caused by moisture and higher TSR value represented better durability and adhesion of the binder and aggregate.

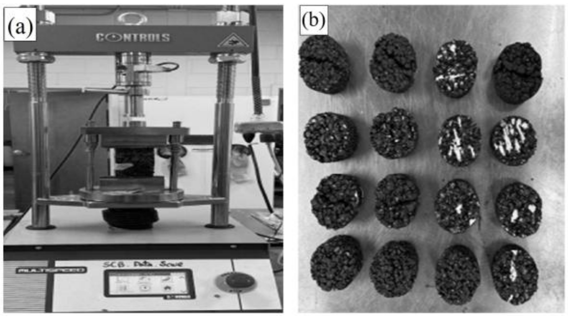


Figure 6: (a) ITS sample under loading condition and (b) Sample after ITS test

3. RESULT AND DISCUSSION

3.1 Rutting Resistance

The HWTT test results demonstrate a strong correlation between GTR content and rutting resistance, though the degree of improvement varied depending on the binder grade. The variation in terminal rut depth with different GTR contents for PG 64-22 and PG 76-22 binders is shown in Figures 7(a) and 7(b), respectively, after 20,000-wheel passes. For PG 64-22, significant improvement occurred only at 15 % GTR, where rut depth decreased by 28.7 % (from 4.46 mm to 3.18 mm). At lower GTR level (5–10%), only marginal changes in rut depth were observed, whereas a higher content (20%) led to a slight increase due to reduced workability and possible phase separation within the mixture. In contrast, the PG 76-22 binder exhibited substantial improvement even at low GTR additions, with an optimum performance at 5% GTR, where the rut depth was reduced by 43.9% (from 4.17 mm to 2.34 mm). However, further increases in GTR content led to a decline in rutting resistance, likely due to excessive binder stiffness and reduced elastic recovery. Overall, the PG 76-22 mixture with 5% GTR provided the most effective rutting resistance, outperforming the PG 64-22 mixture with 15% GTR despite using a smaller amount of modifier. This outcome highlights that an optimized GTR dosage can significantly improve rutting performance while promoting environmental sustainability through the beneficial reuse of waste tire rubber in asphalt pavements.

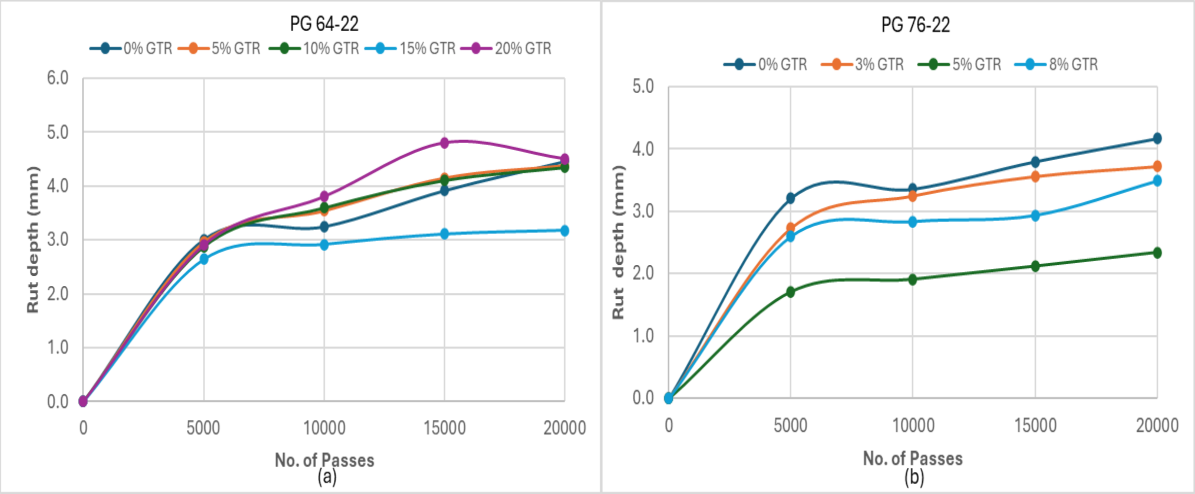


Figure 7: Rut Depth Vs No. of Passes (a) PG 64-22 and (b) PG 76-22

3.2 Stiffness and Fracture Resistance

The effect of GTR content on the stiffness and fracture energy of PG 64-22 and PG 76-22 binders was examined to evaluate its influence on fracture behavior. In the SCB Illinois tests, the PG 76-22 mixture showed a moderate stiffness gain of 3.37% when GTR increased from 0% to 3%, followed by a sharp rise of about 26.3% between 3% and 5%, and a slight drop of 3.77% from 5% to 8%. These results indicate that the optimal stiffness occurred near 5% GTR (Fig. 8a). The PG 64-22 binder exhibited a similar pattern, with stiffness increasing by 5.89% up to 5% GTR, decreasing slightly by 3.67% between 5% and 10%, and then rising marginally by 2.1% at 15%, again suggesting a peak response around 5% GTR (Fig. 9a).

In the SCB Louisiana tests, PG 76-22 displayed a non-linear trend, showing a 7.27% increase from 0% to 3%, a drop of 13.77% between 3% and 5%, and a moderate recovery of 12.97% from 5% to 8% GTR (Fig. 8b). In contrast, PG 64-22 demonstrated a more consistent improvement, with stiffness rising by 17.91% from 0% to 5%, increasing further by 5.79 % from 5% to 10%, before a moderate decline of 11.08% at 15% (Fig. 9b). These trends suggest that the optimum stiffness for PG 64-22 occurred around 10% GTR, while PG 76-22 reached its best balance near 5% GTR.

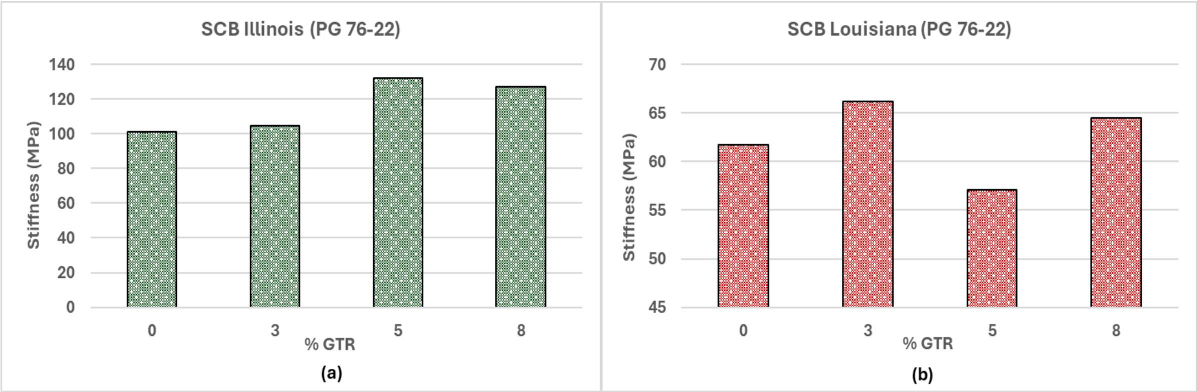


Figure 8: Stiffness Vs GTR% for PG 76-22 binder in (a) (a) SCB-Illinois and (b) SCB- Louisiana method.

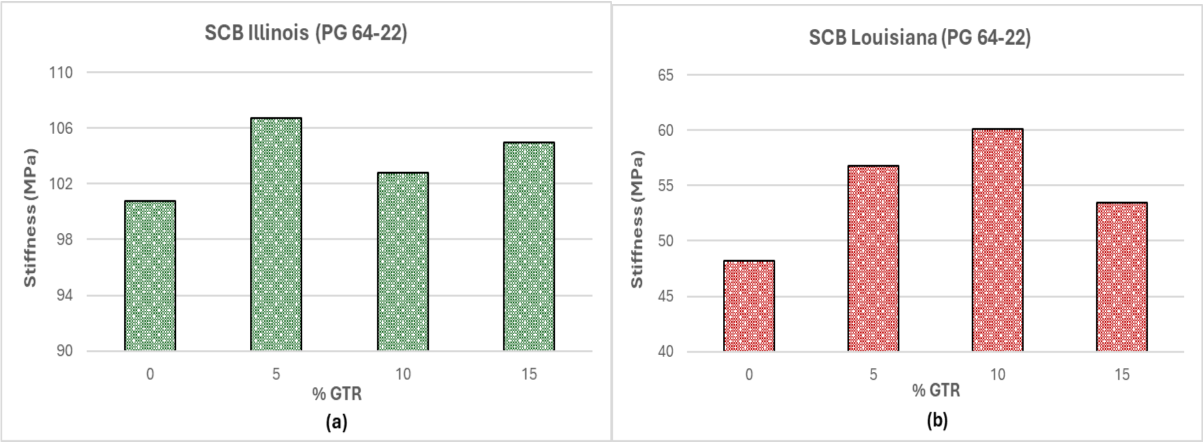


Figure 9: Stiffness Vs GTR% for PG 64-22 binder in (a) SCB-Illinois and (b) SCB- Louisiana method.

In addition, a steady rise in fracture energy was found with GTR addition under all test conditions. In the SCB Illinois tests, PG 76-22 had a moderate increase of 10.05% from 0% to 3%, a steep increase of 53.9% between 3% and 5%, and a slight drop of 12.77% from 5% to 8% (Fig.10a). PG 64-22 had a similar trend which showed an increase of 25.78% up to 5% GTR, 52.50% from 5% to 10% and

5.81% between 10% and 15% which indicates the significant enhancement of fracture energy at higher contents (Fig. 11a).

In the SCB Louisiana tests, PG 76-22 exhibited a percentage increase of 16.18% from 0–3% and 33.54% from 3–5%, followed by a 20.47% decrease from 5–8% (Fig. 10b). In contrast, PG 64-22 exhibited percentage increases of 23.94%, 37.44%, and 11.75% across the successive GTR intervals, indicating a generally increasing trend with higher GTR levels. The largest improvements occurred between 5% and 10% GTR, especially for PG 64-22. PG 76-22 was found to have higher overall fracture energy and stiffness and confirmed to have better resistance to both cracking and deformation. These findings confirm that GTR addition results in higher stiffness and often higher fracture energy that would allow to improve the resistance to cracking and deformation while maintaining sustainable pavement design from the reuse of waste tire rubber.

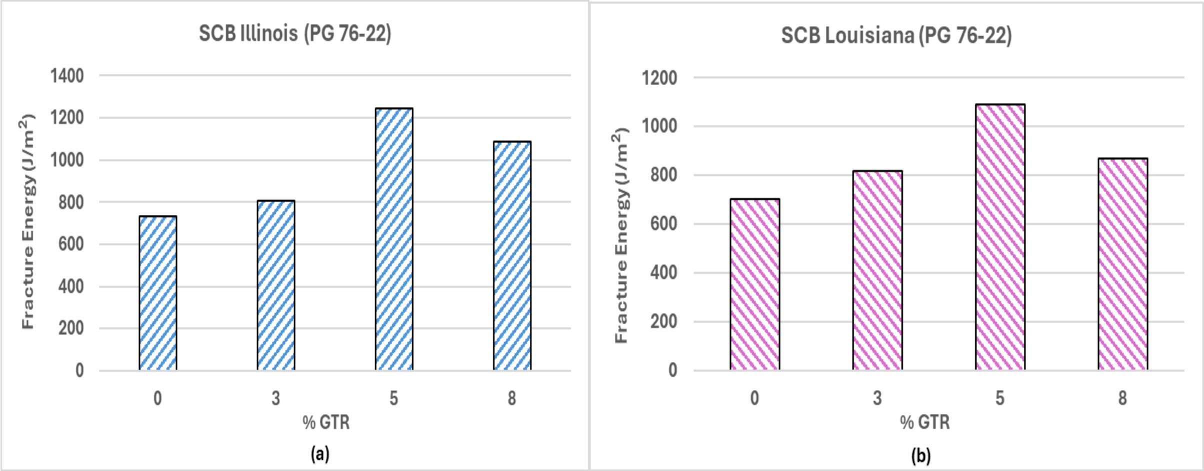


Figure 10: Fracture Energy Vs GTR% for PG 76-22 binder (a) SCB-Illinois and (b) SCB- Louisiana method.

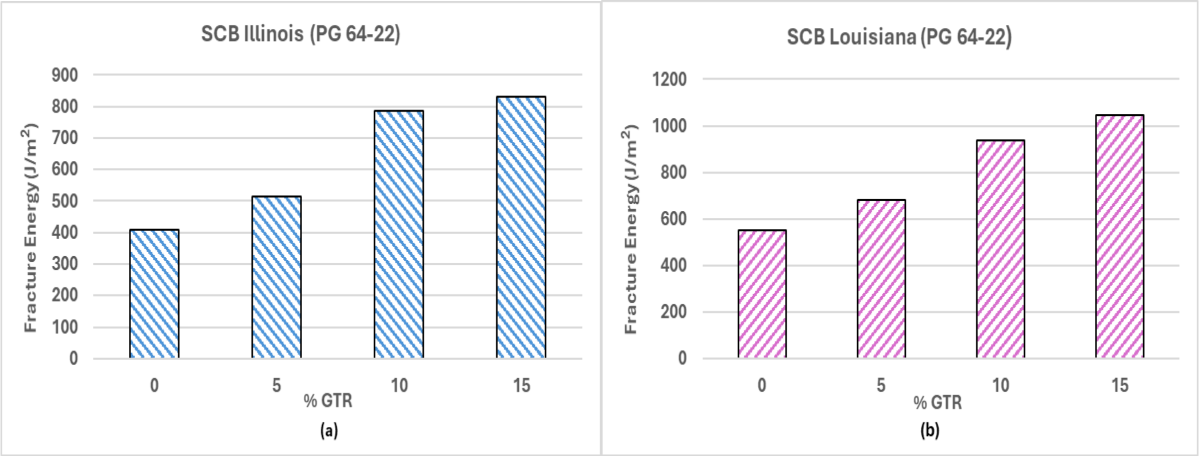
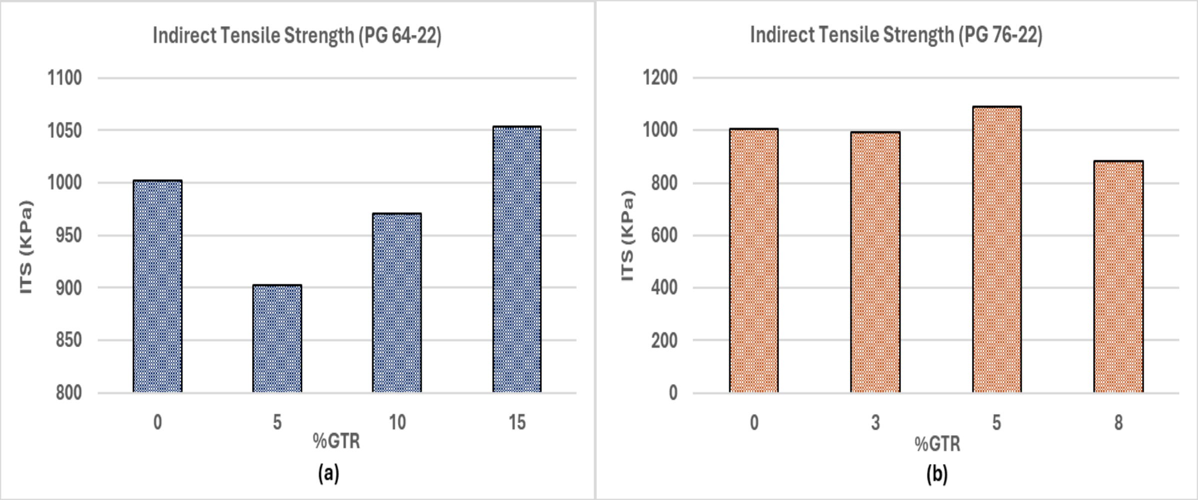


Figure 11: Fracture Energy Vs GTR% for PG 64-22 binder in (a) SCB-Illinois and (b) SCB-Louisiana method.

3.3 Tensile Strength and Moisture Susceptibility

The inclusion of Ground Tire Rubber (GTR) in both PG 64-22 and PG 76-22 asphalt binder resulted in notable increases in tensile properties with little change in moisture resistance. Figure 12 shows the variation of Indirect Tensile Strength (ITS) whereas Figure 13 shows the Tensile Strength Ratio (TSR) for PG 64-22 and PG 76-22 asphalt binders. For the PG 64-22 binder, the ITS value was found gradually increased from 1002.4 kPa for 0% GTR to 1054.1 kPa for 15% GTR. This increase shows that GTR enhanced the stiffness and internal bonding of the mixture. The TSR values remained almost unchanged from 91.5% to 93.5%, which indicates that even with higher GTR content, the mixture retained a good resistance to the effects of moisture. The overall trend appears to show that the GTR addition was strengthening the mixture without having any negative effects on its durability, with the best performance around 15% GTR. For the PG 76-22 binder, the ITS showed the maximum value of 1088.9 kPa at 5% GTR, and then decreased to 883.0 kPa at 8% GTR. A similar trend was noticed for TSR, which slightly declined from 92.8% to 89%. These results suggest that supplementing with too much GTR may decrease the uniformity of the binder and influence the uniformity of how well the binder works in wet conditions.

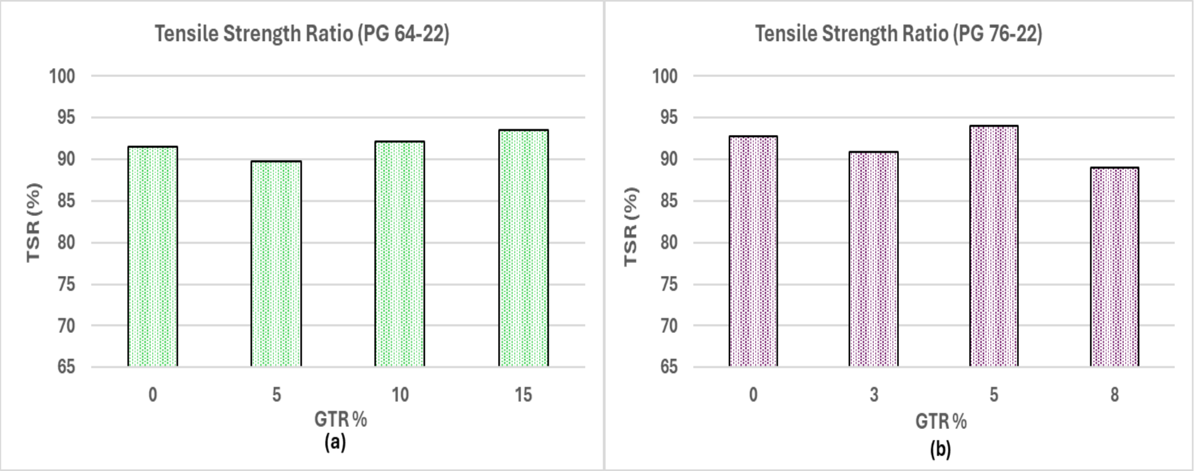
Overall, PG 64-22 exhibited greater improvement with increasing GTR, whereas PG 76-22 was best for a lower GTR level. The results confirm controlled modification of GTR improves durability of asphalt mixtures against moisture damage supporting the use of this product for sustainable and long-lasting pavement application.



(a)

(b)

Figure 12: Indirect Tensile Strength Vs GTR% for (a) PG 64-22 and (b) PG 76-22 binder



(a)

(b)

Figure 13: Tensile Strength Ratio Vs GTR% for (a) PG 64-22 and (b) PG 76-22 binder

4. CONCLUSION

This study evaluated the effects of Ground Tire Rubber (GTR) modification on the mechanical and durability performance of PG 64-22 and PG 76-22 asphalt binders. The results showed that the incorporation of GTR resulted in much better rutting resistance, stiffness and fracture energy, and the best performances were generally obtained at moderate contents in the range of 5% to 10%. For PG 76-22, 5% GTR gave the biggest reduction in rut depth (43.9%), while PG 64-22 was more consistent with its performance gains at higher dosages. The increase in stiffness and fracture energy improved resistance to crack initiation, propagation and permanent deformation, while the Tensile Strength Ratio (TSR) results showed that addition of GTR did not significantly reduce moisture resistance. The study also highlights the environmental benefits of the use of GTR which represents a sustainable solution through the recycling of waste tires and the reduction of the carbon footprint of the asphalt pavements. Overall, the results are positive for the application of binders modified with GTR in asphalt paving, offering a balance between the requirement for mechanical performance and environmental sustainability. Further research can be conducted in the content of GTR fine-tuning the various binder types and regional climates for the best performance.

5. DECLARATION OF USE OF AI

The authors declare that Grammarly (an AI-assisted writing tool) was used solely to improve grammar, spelling, clarity and readability of the manuscript. The tool was not used for generating scientific content, data analysis, interpretation of results, or methodological decisions. All scientific content, analysis, and conclusions are the sole responsibility of the authors.

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