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Research Article

Experimental Study on the Influence of Crumb Rubber on Temperature Susceptibility of Asphalt for Railway Application in the Tropics

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Abstract

The granular sub-ballast in conventional ballasted trackbed structure, though cheap and easy to construct, requires frequent maintenance, and cannot protect the subgrade against water infiltration. However, asphaltic sub-ballast in asphalt-ballast trackbed can reduce stress on the subgrade and provide a waterproofing layer against water infiltration. Asphalt binder is however, susceptible to temperature fluctuations. The aim of this study therefore is to investigate whether the addition of crumb rubber to asphalt binder could reduce the susceptibility of asphalt to temperature, and thus, improve its performance. The main objective of this research is the addition of four different ratios of crumb rubber; 1, 2, 3, and 4%, of size 0.3 mm to bitumen or asphalt 60/70 grade. The results showed that penetration of the asphalt binder reduced from 66.70 to 59.20 mm at 4% rubber content, implying that the modified asphalt became harder with addition of crumb rubber and thus, can withstand temperatures variations in asphaltic pavements. Softening point, used to test temperature susceptibility of bitumen, increased from 49.10 ℃ to 52.80 ℃ at 4% crumb rubber content, implying that crumb rubber modified asphalt can withstand elevated temperatures in asphaltic pavements, in the tropics. Flashpoint increased from 295.20 to 296.12 ℃, fire point also increased from 306.50 ℃ to 308.28 ℃, Specific gravity of the unmodified and crumb rubber-modified asphalt did not change significantly because crumb rubber is not very flammable, Viscosity at 135 ℃ increased from 338.00 to 360.00 cSt at crumb rubber content of 4%, Ductility at 25 ℃ reduced from 122.40 cm to 79.40 cm at 4% crumb rubber content, implying that crumb rubber made asphalt stiffer. This study concludes that crumb rubber can reduce the susceptibility of asphalt to temperature changes.

Keywords

Asphalt for Railways, High and Low Temperatures, Influence, Physical Properties, Temperature Susceptibility, Tropics

1. Introduction

Since trains are able to travel at faster speeds and carry more freight, bituminous sub-ballast is regarded as a feasible option for improving the structural performance and durability of railway sub-structure. As a result, the foundation of structure supporting trains must also evolve both structurally and sustainably. In this regard, the use of high modulus asphalt mixtures can increase the structure's bearing capacity, and the addition of modified asphalt during the production could present an attractive opportunity for improving the infrasttructure's structural efficiency and long-term reliability [11, 17].

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Railway traffic has made extensive use of traditional ballasted rails globally. But the rise in high-speed rail and the expansion of train loading capacities have made it necessary to improve the track substructure by placing stiffer granular layers—one of which is called sub-ballast—between the ballast and the subgrade in order to extend the track's service life and lower maintenance costs. However, this technique might demand thicker granular layers to provide the necessary minimum bearing capacity, thereby consuming a substantial amount of high-quality aggregate.

Therefore, an alternate solution consists of applying hot-mix asphalt, a material frequently used in road pavements [14] between the ballast and subgrade to replace a portion of the traditional granular layers. This material is known as asphaltic sub-ballast [18, 17], this asphaltic subballast reduces the thickness of sub-layers and limits the deterioration of the track geometry to a minimum.

Asphaltic sub-ballast has been extensively utilized in several railway lines, especially high-speed railways, in the US, Italy, and Japan, and other European countries, including Austria, France, and Spain [18, 17]. The asphaltic layer is typically 12 to 15 cm thick and is made up of densely-graded asphaltic mixture, with aggregate sizes no larger than 22 to 25 mm [16]. Generally, the asphaltic mixture is manufactured with the same properties as that used in highways, but its bitumen or asphalt concentration is increased by 0.5% for application as railway sub-ballast compared to what is obtainable for roads. Furthermore, the air void percentage is reduced to 1-3 percent in order to produce an impermeable material.

Furthermore, it has been shown that the use of asphaltic sub-ballast typically results in more uniform track behaviour [7] and it possesses lower vibration acceleration levels [12]. However, research on the short- and long-term effectiveness of asphaltic sub-ballast is required before this system is widely used. This is to ensure that the system meets its primary service requirements, which are mainly impermeability, bearing capacity, stress dissipation, and durability, under the various service conditions that are anticipated when it is applied in railway tracks.

It is also important to consider the fact that temperature fluctuations affect how well asphalt mixes function, becoming more viscous at higher temperatures and more elastic at lower ones [10]. Consequently, the advantages of asphaltic sub-ballast may be dependent on the service temperature, which is vulnerable to considerable fluctuations, especially in the tropics.

Asphalt binder in asphaltic mixture, is characterized by its viscoelastic behavior which dominates many facets of the performance of pavements. The rheological behavior of asphalts is predominantly influenced by temperature and applied loads, which is evidenced between two extremes: purely viscous and purely elastic. An asphalt binder should be elastic for dissipation of energy at low temperatures, without fatigue cracking and viscous at high temperatures to prevent rutting. At ambient temperatures, asphalt is a stable semi-solid. However, exponential increase in traffic and significant variations in daily and seasonal temperatures have shown some limitations in asphalt binder performance [13].

Climate change causes deterioration of the hydrological cycle, economy and pavement structures [19]. In general, climate change will not introduce new consequences for the pavement, but increases the likelihood and scale of deterioration of catastrophic failure. The vulnerability of a pavement to temperature impact of climate change is determined by pavement materials and pavement design. Susceptibility of binders to high temperatures is noticeable in hot months (summer) where air temperatures exceed 30 ℃. The surface temperature of asphalt pavements may increase by 50 ℃ or more, which may reach or exceed the softening point of asphalt [20].

This study assessed the ability of crumb rubber to reducing asphalt susceptibility to temperature, especially in the tropics with elevated temperatures. The choice of crumb rubber is important for four reasons: to protect the environment, promote sustainable construction, reduce the sensitivity of asphalt to temperature fluctuations, and reduce the cost of maintenance.

2. Literature Review

The main reason responsible for damage in railway trackbeds is the damage of subgrade by a process whereby water freely enters into the subgrade. Thus, where this process is allowed to continue, the strength of the subgrade reduces and irreversible damage occurs. This damage such as settlement affects the geometry of the trackbed, leading to rail derailment, extensive and expensive maintenance cost. Due to the rapid development and expansion of the railway infrastructures globally, including Nigeria. One of the most important decisions expected to be taken by countries using the ballasted or all-granular trackbed structure is to prevent water from percolating freely into the subgrade, and this must be done in a sustainable and environmentally-friendly way.

2.1. Sustainable Pavements

Concerns about safeguarding and protecting of the environment have grown in importance in our culture in the last few decades. Political, economic, and social decision-makers are interested in environmental concerns. The preservation of non-renewable resources and the question of resources rank among this concern's most important factors. As a result, a lot of authorities and experts are looking for a way to use renewable resources in an ecologically friendly way. When taking into consideration the difficulties associated to non-renewable resources, such as depleting oil reserves, pavement engineers and researchers are concerned about the usage of environmentally friendly modifiers for asphalt pavement production [8].

The reason for this is because asphalt mixtures use a significant amount of non-renewable resources annually, which strains the ecosystem. As a result, they create regions of extreme heat and difficult issues. Consequently, there has been an increased interest in the usage of materials that could eventually replace non-renewable resources, like bitumen, as it might likely reduce environmental effects like greenhouse gas emissions [9].

2.2. The Environment

Environmental conservation and preservation issues have become an integral aspect of our society in recent years. Environmental challenges have drawn the interest of political, economic, and social decision-makers. Among these concerns, the issue of resources and conservation of non-renewable materials have become one of the most critical considerations. Many authorities and researchers would therefore seek an approach to use renewable material in an environmentally responsible manner. Pavement practitioners, as well as researchers, are concerned with the use of alternative modifiers for asphalt pavement manufacture when considering the issues related to non-renewable resources such as decreasing oil reserves [15].

This is because asphalt mixtures use a significant amount of non-renewable resources annually and cause a great deal of stress on the environment [15]. Because it may be able to reduce environmental effects like releases of greenhouse gases, the usage of materials that could eventually be able to replace non-renewable resources, such as bitumen, has attracted a lot of interest [21].

In view of this, the purpose of this study is to ascertain if it would be feasible to create pavements with excellent mechanical performance and minimal environmental impact to align with the United Nations' ninth sustainable development target [21], which aims to minimize resource and energy consumption through innovation assistance, sustainable industry promotion, and the construction of durable infrastructure.

2.3. Whole-life Cycle Costs

The Nigerian government is finding it difficult to fund capital projects owing to the uncertainty in the oil and gas prices, as well as the vagaries of market forces. Crumb rubber modified asphaltic track is required to reduce the rapid degradation of ballasted tracks, and frequent and costly maintenance, particularly now that all indices indicate that the Nigerian economy is not strong. As a result, using crumb rubber from scrap car tyres is not only cost-effective, it also has a lower environmental footprint, making sure that the air we breathe is safe and the scarce natural resources are preserved for use in the future.

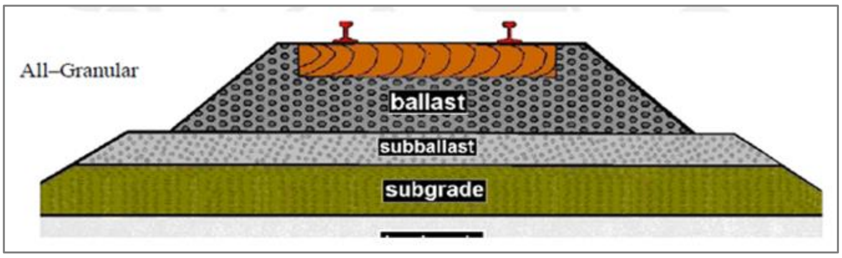

Figure 1. *Layout of Ballasted (All-granular) trackbed structure (Adapted from [17]).*

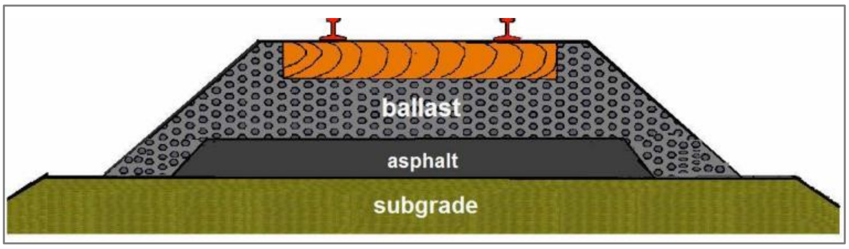

Figure 2. *Layout of Asphalt-ballast trackbed [17].*

3. Materials and Methods

3.1. Materials and Sample Collection

Neat or virgin sample of bitumen or asphalt 60/70 conforming to standard requirements in the Standard Specification for Road and Bridge Construction were sourced from Nigerian National Petroleum Corporation Kaduna. The tests that were done on both the unmodified and crumb rubber modified asphalt were Penetration, Softening point, Flash point, Fire point, Ductility, Viscosity, Specific gravity. The tests were carried out to assess how modification of asphalt with crumb rubber affects the properties of the unmodified asphalt.

3.2. Methods

The tests conducted on both the unmodified and crumb rubber modified bitumen to determine effect of crumb rubber were: Penetration, Softening point, Flash point, Fire point, Ductility, Viscosity, Specific gravity of bitumen samples.

1. Penetration test was done by using a Penetrometer in accordance with [3] standard specifications.
2. Softening point was determined using a Ring-and Ball Apparatus, the heat level under which bitumen sample starts melting is known as softening point and was determined by using a ring and ball apparatus according to ASTM [4] specifications.
3. Flash point and fire point were determined by using the Cleveland Open Cup according to [2] standard specifications, where the temperatures at which the asphalt sample could catch fire, was determined. The temperatures at which the asphalt sample could catch fire were measured using the Cleveland Open Cup in accordance with [2]. This test is important because it guarantees that samples are handled at temperatures where there is no chance of a fire breaking out. The flash point was recorded at the temperature at which it ignited.
4. Ductility was determined by using [1] standard method using a ductility machine called ductilometer. The ductility value of the binder was determined at the point of breaking of the stretched sample.
5. Viscosity test on the neat and modified binders were determined in accordance with [5] standard specifications. The method involves the use of a U-tube modified reverse flow viscometer at 135 ℃.
6. The specific gravity test was performed by using [6] standard method. The sample was heated to a temperature at which it could flow. Water was added to a clean pycnometer, and the combined mass of the pycnometer and water was measured as (B). Weight of the empty pycnometer was taken as (A). The sample was poured into the pycnometer to about three quarters its full capacity without touching the sides of the pycnometer and allowed to cool for one hour and the mass of the pycnometer plus sample taken and noted as (C).

$$\text{Specific gravity} = (C-A)/(B-A)-(D-C).$$

Where,
A= mass of pycnometer.
B= mass of pycnometer + water.
C = mass of pycnometer + sample.
D = mass of pycnometer + sample + water.

4. Results and Discussions

4.1. Test Results

The unmodified and modified bitumen were analyzed to conform to the standards of relevant testing methods, which gave the results as shown in Tables 1 and 2.

Table 1. *Test Results on unmodified Bitumen 60/70 Grade.*

Tests Conducted	Code Used	Code Limits	Test Results (Average)
*Penetration at 25 ℃, 0.1mm	ASTM D5 - 2005	60 – 70	66.70
*Softening Point (℃)	ASTM D36 – 2006	46 – 56	49.10
Flash Point (℃)	ASTM D92-2005	Min. 233	295.20
Fire Point (℃)	ASTM D92-2005	Min. 232	306.50
Ductility 25 ℃ (cm)	ASTM D113, 2007	Min. 50	122.40
Specific gravity at 25 ℃	ASTM D70, 2003	0.97 – 1.06	1.04
Viscosity @ 135	ASTM D4402	Min. 320	358.00

Table 2. *Test Results on Crumb Rubber Modified Bitumen 60/70 Penetration Grade.*

Test description	Results					Code used	Code limits
Crumb rubber added (%)	**0%**	**1%**	**2%**	**3%**	**4%**		
Penetration at 25 ℃ (100g, 5s) 0.1 mm	66.70	64.12	62.31	61.50	59.20	ASTM D2-2005	60-70
Softening Point (℃)	49.10	50.21	51.07	51.80	52.74	ASTM D36-2006	46-56
Flash Point (℃)	295.20	295.40	295.81	296.12	296.80	ASTM D92-2005	Min. 233
Fire Point (℃)	306.50	307.41	307.92	308.28	308.94	ASTM D92-2005	Min. 232
Ductility at 25 ℃ (cm)	122.40	121.15	112.51	92.12	79.40	ASTM D113, 2007	Min. 50
Viscosity at 135 ℃	338.00	341.10	352.18	360.00	363.58	ASTM D4402	Min. 320
Specific gravity at 25 ℃	1.03	1.03	1.04	1.05	1.06	ASTM D70, 2003	0.97-1.06

4.2. Discussions

1. Penetration - The result in Tables 1 and 2 showed that penetration of crumb rubber modified bitumen depends on the amount of crumb rubber added, the penetration values reduced from 66.70 to 59.20 ℃ as more crumb rubber was being added. This implied that modified binders became harder with the addition of crumb rubber and therefore can withstand or contend with fluctuating temperatures in asphalt pavements.
2. Softening Point - The result (Table 2) showed that softening point, a parameter used to measure pavement temperature susceptibility. It increased from 49.10 ℃ to 52.80 ℃ with the addition of more crumb rubber, showing that the addition of crumb rubber to asphalt makes it less susceptible damages caused by temperature changes in asphalt mixtures. This shows that the modified binder is capable of withstanding elevated temperatures. The results obtained fell within the specified limit of 46 – 56 ℃.
3. Flash point - The flashpoint increased from 295.20 to 296.12 ℃. The result obtained was more than the minimum of 233 ℃ as specified by the standard testing method.
4. Fire point - fire point also increased 306.50 ℃ to 308.28 ℃. The result obtained was more than the minimum of 232 ℃ as specified by the standard testing method.
5. Ductility - Ductility at 25 ℃ reduced from 122.40 cm to 79.40 cm as 4% crumb rubber content, thereby making crumb rubber modified asphalt stiffer or harder. This shows that crumb rubber modified asphalt can reduce the susceptibility of asphalt to temperature changes.
6. Viscosity - the viscosity at 135 ℃ increased from 338.00 to 360.00 cSt at crumb rubber content of 4%, implying that the viscosity increased as the asphalt content was increased. The results obtained was more than the minimum of 320 cST specified in the code.
7. Specific gravity - the specific gravity of the unmodified and crumb rubber-modified asphalt did not change much because crumb rubber is not very flammable. All the results obtained in this research fell within the limit of 0.97 to 1.06 specified in the code used.

5. Conclusions

Based on laboratory results on the addition of crumb rubber powder in ratios 0%, 1%, 2%, 3% and 4% by weight of asphalt using the wet process, and its influence on the physical properties of bitumen 60/70 penetration grade, the following conclusions are drawn:

1. The crumb rubber addition to bitumen makes it more flexible and elastic. This improved flexibility could help asphaltic mixtures to carry traffic loads and reduce fatigue cracks from forming.
2. The research showed that penetration of crumb rubber modified asphalt depends on the amount of crumb rubber added. The penetration values reduced from 66.70 to 59.20 ℃, as more crumb rubber was being added. This is because the modified binder became harder when crumb rubber was added, and consequently able to withstand temperature changes in asphalt pavements.
3. The research also showed that softening point, a parameter used to measure pavement temperature susceptibility, increased from 49.10 ℃ to 52.80 ℃, with the addition of more crumb rubber. This means that the addition of crumb rubber to asphalt makes it less susceptible to defects caused by temperature changes, thereby, making crumb rubber modified binder to be capable of resisting or contending with high temperatures in the tropics. This temperature is expected to rise globally and even more in the tropics, as a result of climate change, which makes this study very important.
4. The use of crumb rubber in asphalt helps in protecting

the environment by reducing wastes, especially the non-biodegradable wastes in the society, and conserving natural resources for the next generation.

Abbreviations

ASTM	American Standards Testing Method
CGC	Chinese Geotechnical Company
TETFUND	Tertiary Education Trust Fund

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Author Contributions

Samuel Adejoh Apeh: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – Editing

Adeyeri Joseph Babatola: Review and Supervision

Amu Olugbenga Oludolapo: Review and Supervision

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] ASTM D113-2002: Standard Test Method for Determination of Ductility of Asphalt Materials.

[2] ASTM D92-2003. Standard Test Method for flash and fire points.

[3] ASTM D5-2005. Standard Test Method for Penetration of Bituminous Materials.

[4] ASTM D36-2006. Standard Test Method for the Determination of Softening Points.

[5] ASTM D4402, 2006. Standard test method for viscosity determination of asphalt at elevated temperatures using a rotational viscometer.

[6] D70, 2003. Standard test method for density of semi-solid asphalt binder temperatures using a rotational viscometer (pycnometer method).

[7] CENIT, (2005). Estudio sobre la viabilidad de incorporar capas de sub-balasto con material bituminoso en las lineas de alta velocidad en Espana-Fase 2. 252 pp. Conf. Report.

[8] Farina, A, and Maria, C. Z. (2017). Life cycle assessment applied to bituminous mixtures containing recycled materials: Crumb rubber and reclaimed asphalt pavement. Resour. Conserv. Recycl. http://doi.org/10.1016/j.resconrec.2017.10.015

[9] Graziani, A. (2020). Insights on the United Nations Sustainable Development Goals scope: Are they aligned with a ‘ strong ’ sustainable development ?

[10] Hafeez, I, Hussain, J, Riaz, K, Khitab, A, Hussain, S, Zaidi, B, Farooqi, U, Hayat, A, Ahmed, I, Asif, A. (2013). Influence of time and temperature on asphalt rheological properties, Life Sci. J. 10(2013) 894–898, http://dx.doi.org/10.1002/app.21283

[11] Khairallah D, Blanc J, Couttineau L, Hornych P et al (2019) Monitoring of railway structures of the high speed line BPL with bituminous and granular sublayers. Constr Build Mater 211: 337–348 https://doi.org/10.1016/j.conbuildmat.2019.03.083

[12] Lopez-Pita, A, Teixeira, P. F, Robuste, F. (2004). High speed track deterioration: the role of the vertical stiffness of the track, ProC. Inst. Mech. Eng. Part F: J. Rail Rapid Transit 218(1) (2004) 31–40. http://dx.doi.org/10.1243/0954409043228044411

[13] Pareek, A., Gupta, T., and Sharma, R. K. (2012). Peformance of polymer modified bitmen for flexible pavements. Engineering, Material Science, 32(4), 341 343. https://doi.org/10.1817/ijscer

[14] Pascual-Munoz, P, Castro-Fresno, D, Carpio, J, Zamora-Barraza, D. (2014). Influence of early colour degradation of asphalt pavements on their thermal behaviour, Constr. Build. Mater. 65(2014) 432–439, http://dx.doi.org/10.1016/j.conbuildmat.2014.05.028

[15] Prosperi, E, Bocci, E, BoCci, M. (2022). Effect of bitumen production process and mix heating temperature on the rheological properties of hot recycled mix asphalt, Sustain. Times 14(15). https://doi.org/10. 3390/su14159677

[16] Rose, J. G, Bryson, L. S. (2009). Hot mix asphalt railway trackbeds materials, performance evaluations, and significant implications. International Conference on Perpetual Pavements, Columbus, Ohio, USA, 2009. Corpus ID: 111241949.

[17] Rose, J. G, Teixeira, P. F, Veit, P. (2011). International Design Practices, Applications, and Performances of Asphalt/Bituminous Railway Trackbeds, GEORAIL, Paris, France. https://dot.org/10.1177/0361198120945314

[18] Teixeira, P. F, Ferreira, P. A, Lineas- Pita, A, Casas, A. C, (2009). Bachiller, The use of bituminous subballast on future high-speed lines in Spain: structural design and economical impact, IJR Int. J. Railway 2(2009) 1–7.

[19] Viola, F., and Celauro, C. (2015). Effects of climate change on asphalt binder selection for road construction in Italy. Trans portation Reseach Part D: Transport and Environment 37, 40-47. https://doi.org/10.1016/j.trd.2015.04.012

[20] Willway, T., Reeves, S., and Layla, B. (2008). Maintaining pavements in a changing climate, TSO, print, London. ISBN -10, 0115529837.

[21] Zhao, K, Wang, Y, F. Li, F. (2019). Influence of ageing condi tions on the chemical property changes of asphalt binders, Road Mater. Pavement Des. 22(3). https://doi.org/10.1080/14680629.2019.1637771