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Environmental Contributing in Eco-friendly Techniques in ConstructedRoads: A review

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Abstract

Green road construction is a shining example of environmental stewardship and innovation in the pursuit of sustainable development. This method incorporates environmentally friendly materials and construction methods to create roadways that not only fulfill their intended function but also benefit the environment. Green road construction is changing the way we think about infrastructure development by combining environmental responsibility with functionality through the use of improved bitumen and recyclable materials.One of the most crucial elements is the choice of materials in the development of green roads. Conventional road construction uses a lot of materials with high carbon footprints, such as concrete and regular asphalt. In contrast, green road building makes use of resources such as warm-mix asphalt, bio-based binders, and recycled asphalt pavement (RAP). These materials aid in the preservation of natural resources in addition to lowering greenhouse gas emissions.This study contributes to practical approaches to reducing environmental impact, enhancing resilience, and promoting sustainability in road construction and maintenance, summarizing current knowledge and highlighting best practices. By ensuring that innovations are successfully integrated into ongoing and future projects, this assessment facilitates informed policy and decision-making, promoting sustainable transport systems, and addressing global climate concerns.

Keywords:asphalt, eco-friendly, construction, road, transportation, pavement, sustainable

Introduction

Road pavement networks are essential to many contemporary demands and expectations. Therefore, they must offer safe and effective transportation, sustainable economic and environmental practices, and dependable and easily accessible forms of transportation[1-4].Sustainable development is the morally righteous and conscientious use of natural resources to lessen air pollution and global warming. This sustainability can be increased by combining well-thought-out building materials and techniques with sophisticated designs and procedures.In the fields of environmental sustainability and civil engineering, the idea of "green road construction" is groundbreaking. This approach reduces the environmental impact of road construction by giving priority to the use of eco-friendly materials and methods. It is a reaction to the increasing demand for sustainable development methods, particularly in light of the environmental problems facing the world today.[5]

Green road construction uses creative methods in addition to environmentally safe materials. These include the installation of solar panels in roads to provide renewable energy, the use of permeable pavements to permit water penetration and lessen flooding, and enhanced water drainage systems that lower pollution and runoff.[6-11]It is impossible to overestimate the importance of bitumen and asphalt in the building of green roads. Modified bitumen, especially emulsion bitumen, is primarily responsible for the construction of longer-lasting and more sustainable roads. Its application at a lower temperature lowers pollutants and energy use during construction.[12,13] . There are numerous advantages to building green roads. It prolongs the life and durability of roads while also lessening their negative effects on the environment. Long-term cost reductions may also result from these methods since they require less upkeep and repairs.[14-20]. Despite the obvious benefits, there are drawbacks to using green road construction methods, including greater upfront expenditures and the requirement for certain tools and training. However, these techniques are becoming more practical and widely accepted as a result of ongoing improvements and growing awareness.[21]

The aim of this study is offering insightful information on practical methods for lowering environmental impact, boosting resilience, and advancing sustainability in road construction and maintenance, this review synthesizes current knowledge and highlights best practices. By ensuring that innovations are successfully incorporated into ongoing and upcoming projects, this evaluation facilitates well-informed policy creation and decision-making, promoting sustainable transportation systems and tackling global climate concerns.

Sustainable Materials

The use of cutting-edge sustainable materials is crucial in green road construction for both improved road performance and environmental health. These substances, which include several types of modified bitumen, are essential for extending the life and functionality of road infrastructure.One of these materials are Bitumen Emulsion for Greener Roads, In environmentally friendly road construction, emulsion bitumen—a mixture of bitumen, water, and an emulsifying agent—stands out. Because of its lower application temperatures, it uses less energy and produces fewer pollutants. This substance is perfect for a variety of weather conditions because it bonds to damp surfaces very well.[22-27]

By adding polymers to conventional bitumen, PMB (polymer modified bitumen; PMB) and CRMB (crumb rubber modified bitumen) greatly increase the flexibility, temperature resistance, and durability of asphalt. It has a longer road life and requires less maintenance, making it appropriate for heavy traffic and harsh weather. [28].CRMB offers an environmentally sustainable method of waste management by using recycled tire rubber in bitumen. In line with green construction principles, it improves the road's resistance to a variety of stressors.

It is noteworthy that recycled materials such as recycled concrete aggregate (RCA) and recovered asphalt pavement (RAP) are becoming more popular. These materials provide renewable solutions and lessen dependency on virgin resources, as can bio-based substitutes like bio-asphalt. [29-33], Other environmentally friendly developments in this area include warm-mix asphalt, which is made at lower temperatures, and permeable pavements, which let water infiltration.Moreover, the dedication to environmentally friendly road building is further evidenced by the use of geo synthetics, such as geo grids and geotextiles, for soil stabilization. These materials lessen the demand for natural aggregates and increase road strength, especially in locations with weak soil.[34-41]

In colder locations where hot-mix asphalt is difficult, cutback bitumen—which is created by diluting bitumen with solvents—can be helpful. Although solvents raise environmental issues, efforts are underway to connect their use with environmentally acceptable methods. [42-47]. Even if using these sustainable materials has drawbacks, such as expense and the requirement for specialist equipment, there is no denying their long-term advantages in terms of sustainability, durability, and environmental impact. These materials are becoming more affordable and widely available due to ongoing research and technological advancements. As shown in figure 1.

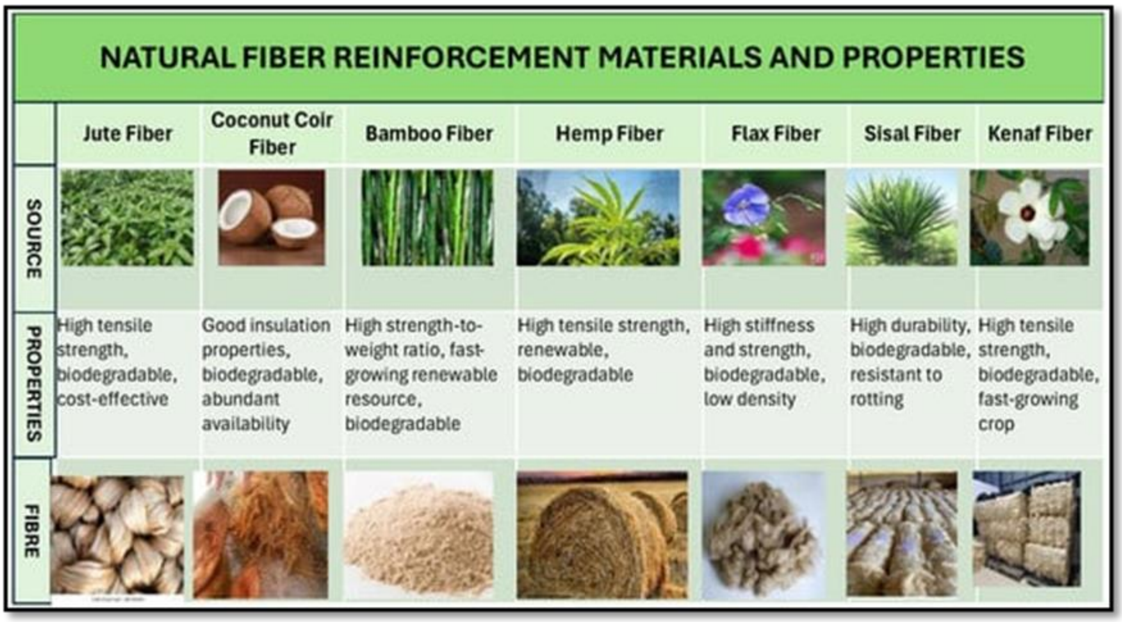

Fig 1: Natural fiber-reinforcement materials and properties for eco-friendly road construction.[48]

Asphalt Implementation for Roadways

Asphalt technology has advanced remarkably in the pursuit of sustainable road construction. These developments are essential for improving the longevity and performance of roads while lessening the negative environmental effects of road construction.

Asphalt Pavement Recycled (RAP)

is acrucial innovation in contemporary road construction is the use of reclaimed asphalt pavement (RAP). By recovering discarded asphalt from outdated roads, RAP considerably lowers the demand for new materials and the resulting environmental impact. Recycling lowers landfill waste while simultaneously conserving natural resources.[49-51]

The possible uses of RAP in highway construction were discussed by Chesner et al. [52]. Some state agencies have claimed significant economic savings when RAP is given [53]. Roadway rehabilitation involves crushing the old HMA and milling the surface to remove the existing asphalt concrete. RAP is the term used to describe the material that is produced by this procedure. The possible economic and environmental advantages and trade-offs of employing RAP in pavements were examined by Ventura et al. [54], and more recently by AL-Qadi et al. [55], Aurangzeb et al. [56], and Del Ponte et al. [57]. However, only a minor amount of RAP was included in these analyses. Furthermore, the financial and environmental benefits of employing RAP rather than conventional (i.e., virgin) materials were not systematically evaluated quantitatively in any of the studies [58]. Therefore, the environmental impact and life cycle economic benefits require a more thorough examination [59].The economic and/or environmental effects at every stage of the material production process were the subject of earlier research on the LCA analysis employing RAP materials (AL-Qadi et al., [55], Aurangzeb et al., [56], and Del Ponte et al., [57]). Therefore, in order to address the potential drawbacks and benefits of employing RAP in the LCA analysis of roadway projects, all stages of the roadway life-cycle performance (i.e., construction, maintenance, and rehabilitation) must be taken into account. The suggested holistic approach technique, which takes into account both the construction and rehabilitation phases, quantifies the life cycle assessment (LCA) environmental benefits and cost savings over the whole performance period of alternative sustainable alternatives. Two real-world case study projects that represented field circumstances for Maryland's major roadways and common pavement building techniques in the northeastern United States were subjected to comparative parametric analysis in order to illustrate the methodology's worth.

An Important Advancement Warm-mix Asphalt

is one of the most important developments (WMA). WMA is made and applied at lower temperatures than conventional hot-mix asphalt. It is a more environmentally friendly choice because of the lower fuel usage and emissions caused by this temperature drop. WMA also prolongs the paving season and enhances working conditions. HMA, WMA, and cold mix asphalt are the various asphalt mixture types used by contractors for building pavements [60]. High energy (fuel) expenditures and greenhouse gas emissions have resulted from the typical production of HMA at temperatures between 155 and 165°C [61]. The normal mixing temperatures for asphalt mixtures are displayed in figure 2.

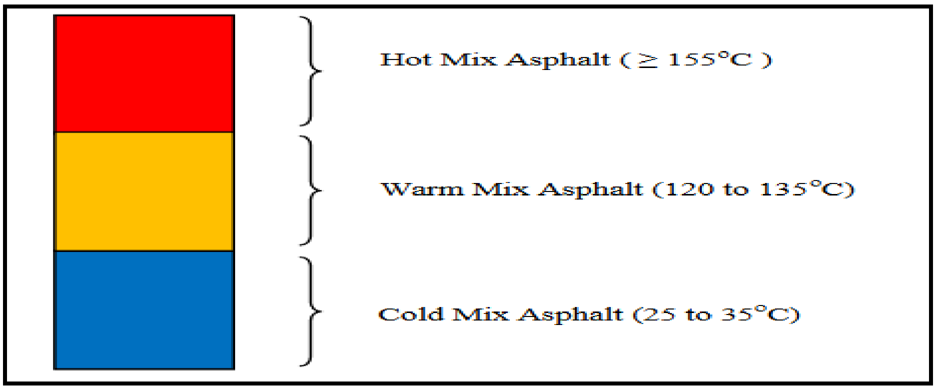

Fig.2:The usual range of temperatures for mixing asphalt mixes [61]

Because the mixes are made closer to the operational temperatures, the WMA technique can lower production temperatures, lower plant odor emissions, extend paving seasons, transport longer distances, open traffic earlier, decrease binder aging, minimize oxidative hardening, and prevent cracking. [62–64]. The rutting properties of WMA mixtures with different heated additives—designated as additives A, B, C, and D—were examined by Zhao et al. [65]. They discovered that the modified mixture with chemical additives and the control mixture had equal rutting characteristics, proving that the chemical additives neither soften nor stiffen the binder.

Petit et al. [66] used the Sasobit type Fisher-Tropsch process (FT) to experimentally assess the mechanical properties of WMA in terms of stiffness and shear fatigue. The experimental results of their study and associated modeling work showed that the addition of WMA additive to the composition of WMA mixes had no effect on their destructive or non-destructive performance when compared to HMA. Among the WMA combinations used in the Caro study's evaluations were Aspha-Min, Evotherm, and Sasobit, which stand for the three different forms of WMA technology [67]. The investigation's findings indicate that the water-based WMA technology Aspha-Min-WMA fine mixes is the most vulnerable to moisture deterioration.

Kim et al. [68] used foaming and emulsion technologies to investigate the performance of WMA in the USA through a laboratory study and field performance. In a study on the use of WMA for airport maintenance in Japan, Su et al. [69] employed a chemical additive (small solid pellets of synthetic wax) made by a Japanese business. They discovered that the WMA produced at a temperature 30°C lower than usual indicated a practical usage because, aside from its moisture-sensitive characteristic, its performance was comparable to or marginally lower than that of the control HMA combination.figure 3 below shows the typical process diagram for a WMA.

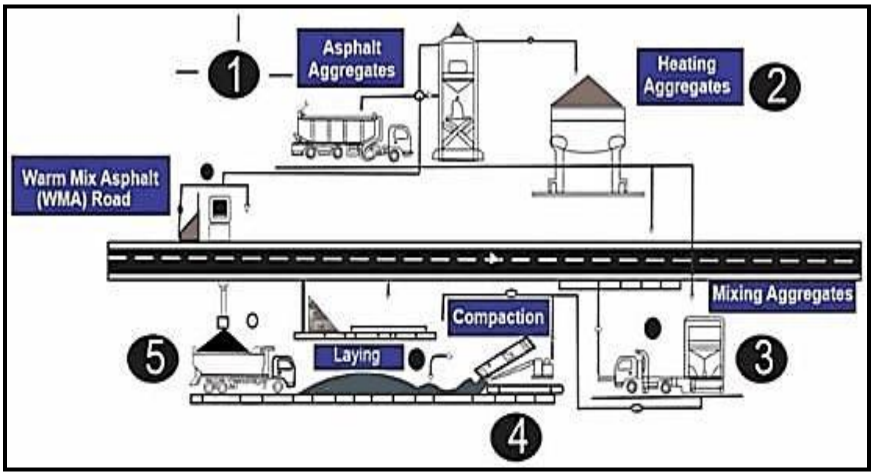

Fig. 3: Warm Mix Asphalt (WMA) process diagram [70]

Porous Asphalt

A new approach to water management in road building is porous asphalt. Because of its permeability, water can flow through it, lowering runoff and averting flooding. By filtering contaminants, this feature can also help recharge groundwater and enhance water quality.Numerous research has been conducted in recent years to assess the impact of preparing PA mixtures using WMA technology. Goh et al. conducted research in the USA [70, 71] on the effectiveness of PA mixtures with 0.25% Advera® as a WMA ingredient and 15% RAP. According to the researchers, a higher RAP proportion may be employed to create warm PA combinations, and the WMA component could enhance the high temperature mixing of RAP-containing mixtures.

Aman [72] assessed the impact of water sensitivity on heated porous asphalt that incorporates Sasobit in a more recent investigation. He constructed the warm PA mixtures using the Dutch PA gradation while adhering to Malaysian quarry practices, and he employed hydrated lime and Pavement Modifier (PMD) as anti-stripping additives. Additionally, the results demonstrated that the warm PA mixes with PMD and hydrated lime could be compressed to temperatures as low as 135°C and 125°C, respectively. As shown in figure 4.

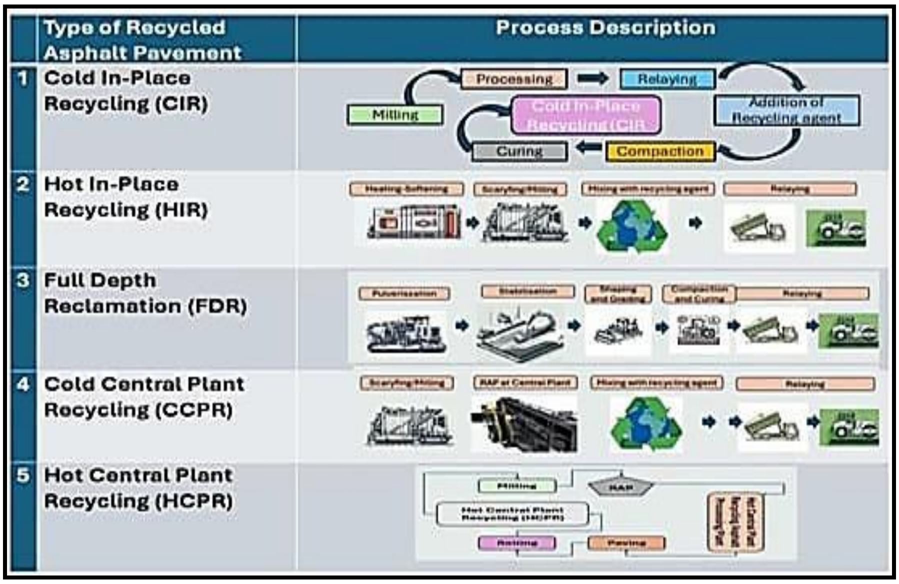

***Fig. 4* :** Types of Recycled Asphalt Pavement (RAP) and processes as cited in the literature.[48]

Bio-Asphalt

is a revolutionary development in asphalt technology that provides an environmentally friendly substitute for petroleum-based asphalt by using renewable resources such awmas vegetable oil or tree resin as a binder. This innovation is in line with international efforts to lessen dependency on fossil fuels.

Bio-asphalt, a plant-derived asphalt, can be used as a rejuvenating material in accordance with environmentally friendly and sustainable technology because it is a fraction of bio-oil made from biomass obtained from the pyrolysis process (rapid heating of waste materials oxygen-free farms, as well as carbonization processes)[73], agricultural or plantation waste containing lignin [74], industry, and livestock. Various materials, such as sawdust, cooking oil, straw [75], pine wood [76], and coconut shell [77], have been used to create bio-asphalt. Based on rheological, chemical structure, and asphalt morphological tests, [78] investigated the potential of straw bio-asphalt (BioST) and coconut shell bio-asphalt (BioCS) as fluxing materials. The study suggests that bio-asphalt could be used as a rejuvenating agent for aged asphalt (RAP bitumen).

[79] examines the benefits of adding bio-asphalt made from coconut shell (BioCS) and straw (BioST) to asphalt mixtures that incorporate recovered asphalt pavement (RAP). Four mixtures' laboratory performance characteristics and the binders that were taken out of them were determined and compared as part of the study. The outcome shown that bio-asphalt was successful in raising the 30% RAP mix's performance to levels comparable to those of the virgin mix. Future developments in asphalt for environmentally friendly roads appear bright. More eco-friendly materials, better recycling methods, and cutting-edge applications that further lessen the carbon footprint of road building are anticipated as a result of ongoing research and development. As shown in figure 5.

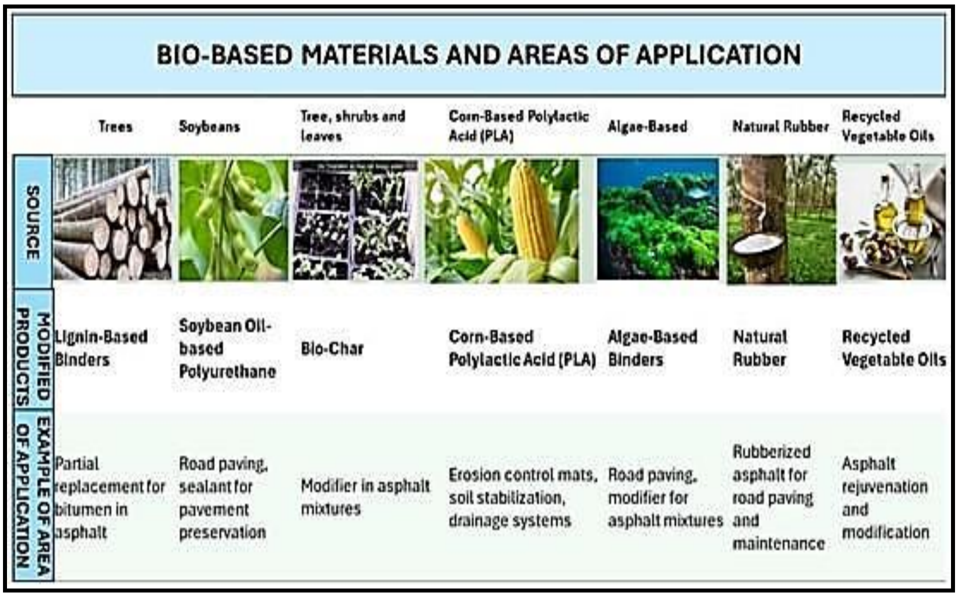

Fig. 5: Bio-based materials and areas of application.[48]

Cost-Effectiveness

Cost-effectiveness is a key consideration in the field of sustainable road construction. A closer look finds long-term economic benefits that make sustainable road development a financially viable option, despite initial preconceptions that eco-friendly materials and techniques may be more expensive.Significant long-term savings can result from the use of long-lasting, environmentally friendly materials such crumb rubber modified bitumen (CRMB), polymer modified bitumen (PMB), and emulsion bitumen. These materials minimize the road's overall lifecycle cost by reducing the need for regular repairs and maintenance, even though they may be more expensive up front.[80]

Lower environmental expenses are another benefit of using green building techniques while building roads. Utilizing recycled resources, such as bio-based goods and recovered asphalt pavement (RAP), reduces the demand for new raw materials, which lowers the cost of waste management and material procurement. In addition to, using warm-mix asphalt and emulsion bitumen are examples of sustainable road construction techniques that reduce emissions and energy use throughout the application and production stages. This lowers the energy expenses related to road construction while also improving the environment.[81-84]

For sustainable infrastructure projects, numerous governments and international organizations provide money, subsidies, and incentives. The initial increased costs of utilizing eco-friendly materials and technologies in road construction can be considerably mitigated by these financial incentives.[85] Even though there are obvious long-term advantages, adopting sustainable practices might be difficult due to factors including higher initial costs and the requirement for certain tools and training. However, these obstacles are progressively vanishing as eco-friendly methods gain popularity and technology develops.

Improving the Durability of Roads

The improvement of road durability is a top priority in the field of green road construction. In addition to achieving environmental goals, green construction techniques greatly increase the durability and resilience of road infrastructure.In order to increase the longevity of roads, advanced materials including Polymer Modified Bitumen (PMB), Crumb Rubber Modified Bitumen (CRMB), and Emulsion Bitumen are essential. Road longevity is increased by these materials' exceptional resistance to environmental stresses, high traffic volumes, and temperature swings.[86]

The ultimate qualities of PMB can be improved by adding polymers to bitumen in order to create binary [87–89] or multicomponent blends (MC) [90,91], according to several studies. This results in materials with improved properties for applications where bitumen alone would not function well. Studies that seek to optimize the various mixes to enhance qualities and lessen frequent failure causes in asphalt mixtures while lowering manufacturing costs are uncommon, despite significant advances in properties.

Prior research has demonstrated that adding these kinds of polymers improves PMB characteristics. For example, bitumen has been treated with SBS to lessen cracking and rutting [92,94,97]; PW to lessen rutting [90,91,95,96]; and CR to lessen cracking and rutting, but at lower levels than those achieved with SBS or PW [93,98,100]. table 1 also displays some of these polymer modifiers' primary attributes.

Table 1: properties and characteristics of base bitumen and polymer modifiers.[101]

	Value
Bitumen	
Penetration 25 °C (dmm)	83
Softening point (°C)	64
SARA analysis (%)	
Asphaltenes	12
Resins	36
Aromatics	38
Saturates	14
SBS	
Total styrene (over polymer)	20
Hardness shore A	60
PW	
Viscosity 140 C (cps)	80
Penetration 25 (dmm)	1
Softening point (°C)	130
Melting temperature (C)	122

Recycled materials like Recycled Asphalt Pavement (RAP) and Recycled Concrete Aggregate (RCA) boost the longevity of roads. It has been demonstrated that these materials provide strong and durable road surfaces that function on par with, and occasionally even better than, their virgin equivalents.In addition to efficiently managing water runoff, innovative pavement designs like porous or permeable pavements also lessen the strain on road surfaces, increasing their durability. [102]. Better water drainage made possible by these design guards against erosion and water damage beneath the road surface.

An additional layer of strength and stability is added when geosynthetics, such as geotextiles and geogrids, are used into road construction. These materials enhance the structural integrity of roads and more equally distribute loads, particularly in regions with unstable or weak soils. Using energy-efficient building methods, including warm-mix asphalt technology, improves the roads' overall durability and quality. By ensuring improved pavement layer compaction and bonding, these methods produce road constructions that are more resilient.[103] , Carroll et al. [104] investigated the strengthening techniques used with geogrids on asphalt roadways. They claimed that geogrid reinforcement enables a 50% reduction in the thickness of the granular base while still lowering permanent deformations in flexible pavement systems, based on equal load deformation performance.

To improve the bearing capacity ratio and determine their subgrade modulus, Schriver et al. [104] experimentally investigated geogrid-reinforced lightweight aggregate beds. The experiment demonstrated that the lifespan of paving roads is considerably increased by placing reinforced geogrid at the sub-base/aggregate contact.Milligan et al. [105] conducted monotonic plate load testing on a large scale. The study found that at a 1.5-inch settlement, adding geogrid reinforcement increased pavement thickness by 2 inches.Chan et al. [106] conducted extensive field research. The subgrade used in the investigation had a CBR of 2.6% and was covered in a layer of crushed granules at the right moisture content.

Giroud and Han [107] used the field study conducted by Watts et al. (2004) to investigate the impact of the geosynthetic fabric's tensile strength at 5% strain.The efficiency of geogrid reinforcement installed in three distinct locations was examined by Moayedi et al. [108]. (for example, 50, 25, and 5 cm out from the base of the model).Tang et al. [109] examined the impact of geogrid properties on subgrade stabilization using extensive direct shear experiments.The long-term advantages in terms of road longevity and lower maintenance costs are indisputable, even though putting these green building techniques into practice may initially bring difficulties like greater upfront expenditures or the requirement for specialist equipment.

The conventional test methods still used to evaluate durability are frequently out of date and not always appropriate to evaluate new goods, even if the future of road construction demands more robust designs. For instance, an "accelerated weathering machine" that efficiently simulates the effects of environmental factors, mainly sunlight and water, on the performance of the materials in a comparatively short amount of time, ensuring that the exacting level of durability is met for both customers and compliance. This enables the group to test every product under strong UV radiation. In order to extend the lifespan of the products and guarantee their long-term performance and durability, it can bealso investigating new polymers and chemical additives as part of future emphasis.

Creative Methods for Building Eco-Friendly Roads

Innovative methods are constantly being developed in the field of environmentally friendly road construction to satisfy the twin objectives of functional excellence and environmental sustainability. These methods guarantee long-term performance and cost-effectiveness while also lessening the environmental impact of road developmentA cutting-edge technique called Cold In-Place Recycling (CIR) rebuilds worn-out pavements by reusing existing road material. During this procedure, the old pavement is milled, mixed with additives if needed, and then relayed at room temperature. CIR drastically lowers the requirement for new materials as well as the corresponding emissions and energy use.[110]

According to Wagoner et al. [111], who tested four mixtures with different compositions, compared to other indirect measurements like tensile strength, the fracture energy appears to be a far better indicator of the material's resistance to fracture.They showed that after performing dynamic modulus and creep compliance tests on the same specimen, the DCT test can determine the fracture parameters of asphalt concrete specimens taken from field cores. The fracture energy method made a clear distinction between the materials based on variations in the characteristics of the binder.

After coring three field projects that produced six essentially distinct mixtures, Kim et al. [112] got a DCT sample. According to the visual field crack assessment, these combinations were supposed to exhibit notably varying degrees of fracture resistance. They showed a reasonable correlation between the field performance of the pavement portions under investigation and the fracture energy measured in the lab based on the observations.TheSCB test's capacity to assess HMA's low temperature fracture resistance was assessed by Li and Marasteanu [113]. The findings showed that the test temperature had a significant impact on the low temperature cracking resistance.The failure processes were interpreted and examined using a three-dimensional (3D) finite element (FE) model. in the SCB test was confirmed by Elseifi et al. [114] in a related work.as shown in figure6.

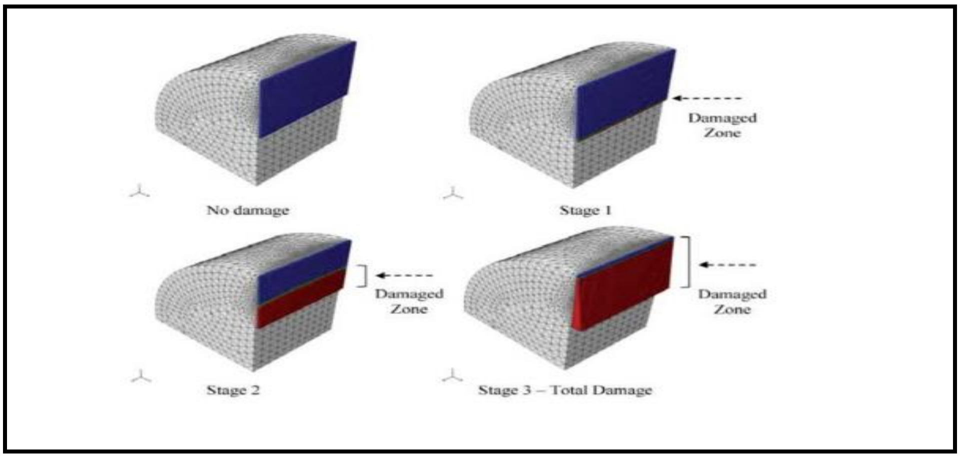

Fig.6:Damage evolution in the SCB test [114].

Reclamation in Full (FDR) another environmentally friendly method that works well for badly damaged roads is Full-Depth Reclamation (FDR). To create a solid, fresh foundation layer, FDR entails pulverizing the pavement's whole thickness as well as some of the underlying materials, then adding stabilizing chemicals and compacting. This approach reduces the environmental impact of road construction while conserving resources.Solar highways and photovoltaic pavements represent a major leap in environmentally friendly road construction. Roads could become sustainable energy sources thanks to these creative pavements that use solar cells to create electricity. By producing clean energy, this technology delivers value in addition to helping the environment.

Applying Cutting-Edge Geosyntheticsmodern road building relies heavily on advanced geosynthetics. Road durability, drainage, and soil stabilization are all enhanced by these materials. Their application results in more sturdy and stable road construction, particularly in regions with difficult soil or topography. [115]Wildlife Crossings and Green Bridges One innovative method for building environmentally friendly roads is to include wildlife crossings and green bridges. By lessening the negative effects of highways on animals, these structures aim to increase ecological connectedness and biodiversity. They provide as evidence of the comprehensive strategy used in environmentally friendly road building.

Overcoming Obstacles with Innovative Approaches Even while these cutting-edge methods pose significant difficulties in terms of technical know-how and upfront costs, they have enormous long-term advantages for environmental preservation, road quality, and sustainability.[116]

Conclusions

Although they are necessary for sustainable growth, green road construction projects have their own set of difficulties. For eco-friendly road construction projects to be implemented successfully and last a long time, these issues must be resolved.Finding a balance between sustainability and cost is one of the main issues in building green roads. When compared to conventional approaches, sustainable materials and practices might frequently be more expensive upfront. But emphasizing the long-term financial and ecological advantages—like lower energy and maintenance expenses—helps defend these upfront expenditures.

Adopting cutting-edge methods like full-depth reclamation (FDR), cold in-place recycling (CIR), and the use of sophisticated geosynthetics calls for specific tools and technical know-how. Finding and deploying these new technologies might provide logistical difficulties, particularly in areas with restricted access to such resources.To overcome these obstacles, ongoing research and development are crucial. R&D expenditures contribute to the advancement of material science, the enhancement of construction methods, and the creation of more economical and effective solutions for environmentally friendly road building.

In order to address environmental issues while preserving the effectiveness and longevity of road infrastructure, green road development has become a crucial solution. This thorough investigation has covered a wide range of topics, from the application of environmentally friendly materials like recycled asphalt and emulsion bitumen to cutting-edge methods like cold in-place recycling and porous pavements. Higher initial prices and technical complexity were also mentioned, highlighting the significance of public awareness, research, and development in overcoming these obstacles.In the end, building green roads is a big step toward sustainable development since it not only shows environmental responsibility but also provides long-term functional and economic advantages.

Author Contribution

This review was written before. H.J.A. and The author, H.J.A., gave his approval to the final manuscript.

References

[1] Shanbaraa, H. K., DulaimibA., Al-MansooriaT., Al-BusaltaneS., HerezfM., SadiquegM., Abdel-Wahedh,**T.** The future of eco-friendly cold mix asphalt" , *Renewable and Sustainable Energy Reviews, 149,2011. 2021.*

[2] Thives, L. P. , Ghisi, E. Asphalt mixtures emission and energy consumption: a review. *Renew Sustain Energy Rev 2017;72:473–84.*2020.

[3] Dulaimi, A., Shanbar,a H. K., Jafer H., Sadique M. An evaluation of the performance of hot mix asphalt containing calcium carbide residue as a filler. *Construct Build Mater;261:119918. 2020.*

[4] Shanbara, H. K., Ruddock, F. , Dulaimi, A., Atherton, W. Cold and hot asphalt pavements modelling. In: Bearing capacity of roads. *Railways and Airfields; 2017.*

[5] Dulaimi, A., Al Nageim, H., Ruddock, F., Seton, L. A novel cold asphalt concrete mixture for heavily trafficked binder course. *Int J Civil, Environ Struct Construct Arch Eng;9(15):734–8. 2015.*

[6] Hurle,y G. C., Prowell, B. D. Evaluation of Aspha-Min zeolite for use in warm mix asphalt. *NCAT Rep 2005. 05-04, /rep05-04.pdf.2005.*http://www.eng.auburn.edu/research/center s/ncat/files/reports.

[7] Hurle,y G. C., Prowell, B. D.. Evaluation of Sasobit for use in warm mix asphalt. *NCAT Rep;5(6):1–27.2005.*

[8] Hurle,y G. C., Prowell, B. D.. Evaluation of Evotherm for use in warm mix asphalt. *NCAT Rep ;2:15–35.2006.*

[9] Prowell, B. D. , Hurley, G. C., Crews, E. Field performance of warm-mix asphalt at national center for asphalt technology test track. *Transport Res Rec 2007; (1):96–102. 1998.*

[10] Wasiuddin, N. M., Selvamohan, S., Zaman, M. M., Guegan, M. L.. Comparative laboratory study of sasobit and aspha-min additives in warm-mix asphalt. *Transport Res Rec;1998(1):82–8.*2007.

[11] Shanbara, H. K., Dulaimi, A., Ruddock, F., Atherton, W. The linear elastic analysis of cold mix asphalt by using finite element modeling. *In: The second BUiD doctoral research conference; 2016.*

[12] Shanbara, H. K., Ruddock, F., Atherton, W. Stresses and strains distribution of a developed cold bituminous emulsion mixture using finite element analysis. *Sci. Technol. Behind Nanoemul.:9. 2018.*

[13] Dulaimi, A., Nageim, H. A., Ruddock, F., Seton, L. Laboratory studies to examine the properties of a novel cold-asphalt concrete binder course mixture containing binary blended cementitious filler. *J Mater Civ Eng ;29(9). 2017.*

[14] Querol, N., Barreneche, C., Cabeza, L. F. Method for controlling mean droplet size in the manufacture of phase inversion bituminous emulsions. *Colloid Surface PhysicochemEng Aspect;527:49–54.2017.*

[15] Shanbara, H. K., Ruddock, F., Atherton, W. Predicting the rutting behaviour of natural fibre-reinforced cold mix asphalt using the finite element method. *Construct Build Mater;167:907–172018.*

[16] Shanbara, H. K., Shubbar, A., Ruddock, F., Atherton, W. Characterizing the rutting behaviour of reinforced cold mix asphalt with natural and synthetic fibres using finite element analysis. *In: Advances in structural engineering and rehabilitation. Springer; p. 221–7. 2020.*

[17] Shanbara, H. K., Ruddock, F., Atherton, W. Improving the mechanical properties of cold mix asphalt mixtures reinforced by natural and synthetic fibers. *In: International conference on highway pavements & airfield technology; 2017.*

[18] Dulaimi, A., Al Nageim, H., Hashim, K., Ruddock, F., Seton, L. Investigation into the stiffness improvement, microstructure and environmental impact of a novel fast- curing cold bituminous emulsion mixture. *In: Eurasphalt and eurobitume congress. Brussels, Belgium: European Asphalt Pavement Association (EAPA) and Eurobitume; 2016.*

[19] Dulaimi, A., Al Nageim, H., Ruddock, F., Seton, L. Assessment the performance of cold bituminous emulsion mixtures with cement and supplementary cementitious material for binder course mixture. *In: The 38th international conference on cement microscopy; [Lyon, France]. 2016 .*

[20] Al Nageim, H., Dulaimi, A., Ruddock, F., Seton, L. Development of a new cementitious filler for use in fast-curing cold binder course in pavement application. *In: The 38th international conference on cement microscopy; p. 167–80. Lyon, France.2016.*

[21] Wasim, M., Vaz Serra, P., Ngo, T. D. Design for manufacturing and assembly for sustainable, quick and cost-effective prefabricated construction – a review. *Int J Construct Manag:1–9.*2020.

[22] Dinis-Almeida, M., Castro-Gomes, J., Sangiorgi, C., Zoorob, S. E., Afonso, M. L. Performance of warm mix recycled asphalt containing up to 100% RAP. *Construct Build Mater;112:1–6. 2016.*

[23] Vaitkus, A., ˇCygas, D., Laurinaviˇcius, A., Vorobjovas, V., Perveneckas, Z. Influence of warm mix asphalt technology on asphalt physical and mechanical properties. *Construct Build Mater ;112:800–6*. 2016.

[24] Shanbara, H. K., Ruddock, F. , Atherton, W. Rutting prediction of a reinforced cold bituminous emulsion mixture using finite element modelling. *ProcediaEng; 164:222–9, 2016.*

[25] Al-Hdabi, A. High strength cold rolled asphalt surface course mixtures. *In: Department of Civil engineering. Liverpool: Liverpool John Moores University; 2014.*

[26] Jenkins, K. J. Mix design considerations for cold and half-warm bituminous mixes with emphasis of foamed bitumen. *Stellenbosch: Stellenbosch University; 2000*

[27] Al-Busaltan, S. Development of new cold bituminous mixtures for road and highway pavements. In: School of built environment. *Liverpool: Liverpool John Moores University; 2012.*

[28] Herez, M. Development of a new high performance cold mix asphalt. *In: Department of Civil engineering. Liverpool: Liverpool John Moores University; 2019.*

[29] Dulaimi, A. Development OF a new cold binder course emulsion asphalt. *In: Department of Civil engineering. Liverpool: Liverpool John Moores University; 2017.*

[30] Nicholls, J.C. Asphalt surfacings. *CRC Press; 1998.*

[31] Robinson, R., Thagesen, B. Road engineering for development. *CRC Press; 2004.*

[**33] Needham, D**. Developments in bitumen emulsion mixtures for roads. *University of Nottingham Nottingham; 1996.*

[34] Thanaya, I. Improving the performance of cold bituminous emulsion mixtures (CBEMs) incorporating waste materials. *2003.*

[35] Ojum, C. K. The design and optimization of cold asphalt emulsion mixtures. *University of Nottingham; 2015*.

[36] Kuna, K.K., Mix design Considerations and performance Characteristics of foamed bitumen mixtures (FBMs)., *University of Nottingham: Nottingham, UK.2014.*

[37] Al-Busaltan, S. Development of new cold bituminous mixtures for road and highway pavements. *Liverpool John Moores University; 2012.*

[38] Jain, S., Singh, B. Cold mix asphalt: an overview. *J Clean Prod ;280:124378.2021.*

[39] Nikolaides, A. F. Design of dense graded cold bituminous emulsion mixtures and evaluation of their engineering properties. *University of Leeds; 1983.*

[40] Dulaimi, A., Al Nageim, H., Ruddock, F., Seton, L. Microanalysis of alkali-activated binary blended cementitious filler in a novel cold binder course mixture. *In: The 38th international conference on cement microscopy; [Lyon, France].2016.*

[41] Liebenberg, J.,Visser, A. Towards a mechanistic structural design procedure for emulsion-treated base layers. *J South AfrInst Civil Eng= J die Suid-AfrInstSiviele Ingenieurswese;46(3):2–9.2004.*

[42] G´omez-Meijide, B., P´erez, I. A proposed methodology for the global study of the mechanical properties of cold asphalt mixtures. *Mater Des ;57:520–7. 2014.*

[43] **Doyle, T. A., McNally, C., Gibney, A., Tabakovi´, C. A.** Developing maturity methods for the assessment of cold-mix bituminous materials. *Construct Build Mater;38: 524–9.2013.*

[44] Oruc, S., Celik, F., Akpinar, M.V. Effect of cement on emulsified asphalt mixtures. *J Mater Eng Perform ;16(5):578–83. 2007.*

[45] Ibrahim, H. S.. Assessment and design of emulsion-aggregate mixtures for use in pavements. *University of Nottingham; 1998.*

[46] Al-Busaltan,S., Al Nageim, H., Atherton, W., Sharples, G. Mechanical properties of an upgrading cold-mix asphalt using waste materials. *J Mater Civ Eng;24(12): 1484–91. 2012.*

[47] Al-Hdabi, A., Al Nageim, H., Ruddock, F., Seton, L. Development of sustainable cold rolled surface course asphalt mixtures using waste fly ash and silica fume. *J Mater CivEng;26(3):536–43*.2014.

[48] Tafida, A., Alaloul, W.S., Zawawi, N.A.B.W., Musarat, M.A.; Abubakar, A.S. A Review of Eco-Friendly Road Infrastructure Innovations for Sustainable Transportation. *Infrastructures9*, 216.2024. https://doi.org/10.3390/infrastructures9120216

[49] Lee, J.; Edil, T.B.; Benson, C.H.; Tinjum, J.M. Building Environmentally and Economically Sustainable Transportation Infrastructure: Green Highway. *J. Constr. Eng. Manag. 139.2013.*

[50] Lee, J.C.; Edil, T.B.; Tinjum, J.M.; Benson, C.H. Quantitative Assessment of Environmental and Economic Benefits of Recycled Materials in Highway Construction. *Transp. Res. Rec. 2158, 138–142. 2010.*

[51]National Academies of Sciences, Engineering, and Medicine. Recycling and Reclamation of Asphalt Pavements Using In-Place Methods; The National Academies Press: *Washington, DC, USA, 2011.*

[52]Chesner, W., Collins, R., MacKay, M. User Guidelines for WasteandBy ProductMaterialsinPavementConstruction;*FHWA-RD-97-148; Federal Highway Administration: McLean, VA, USA, 1998.*

[53] Horvath, A. A Life-Cycle Analysis Model and Decision-Support Tool for Selecting Recycled Versus Virgin Materials for Highway Applications; *RMRC Research Project No 23; Federal Highway Administration: Washington, DC, USA, 2004.*

[54]Ventura, A.; Monéron, P.; Jullien, A. Environmental Impact of a Binding Course Pavement Section, with Asphalt Recycled at Varying Rates. Road Mater. Pavement Des., 9, 319–338.2008.

[55] Al-Qadi, I.L.; Elseifi, M.; Carpenter, S.H. Reclaimed Asphalt Pavement—A Literature Review; *FHWA-ICT-07-001; Illinois Department of Transportation: Springfield, IL, USA, 2007.*

[56] Aurangzeb, Q.; Al-Qadi, I.L.; Ozer, H.; Yang, R. Hybrid Life Cycle Assessment for Asphalt Mixtures with High RAP Content. Resources, *Conservation and Recycling; Elsevier: Philadelphia, PA, USA, Volume 83.2014.*

[57] Del Ponte, K.; Madras Natarajan, B.; Pakes Ahlman, A.; Baker, A.; Elliott, E.; Edil, T.B. Life-Cycle Benefits of Recycled Material in Highway Construction. Transp. *Res. Rec., 2628, 1–11.2017.*

[**58] Goulias, D.D.; Zhang, Y.; Aydilek, A.** Sustainability Assessment of Roadways through Economic and Environmental Impact Life Cycle Analysis. *Int. J. Comput. Eng. Res., 8, 1–8. 2018.*

[59] Pavement Life-Cycle Assessment Tool for Environmental and Economic Effects Version 2.0. *Consortium on Green Design and Manufacturing, University of California, Berkeley, 2021.* Available online: https://rmrc.wisc.edu/palate/

[60] Garber, N.J. and Hoel, L.A.. Traffic and Highway Engineering. Pacific Grove: *Brooks/Cole. 3rd ed. 2001.*

[61] Goh, S.W. Development and Improvement of Warm-Mix Asphalt (WMA) Technology. *Thesis Ph.D. Michigan Technological University.2011.*

[62] Shang, L., Wang, S., Zhang, Y. and Zhang, Y. Pyrolyzed wax from recycled cross-linked polyethylene as warm mix asphalt (WMA) additive for SBS modified asphalt. *Construction and Building Materials. In Press, Corrected Proof.2010.*

[63] Kim, H. Performance evaluation of SBS modified asphalt mixtures using warm mix technologies. *Thesis Ph.D. Clemson University.2010.*

[64] Silva, H.M.R.D., Oliveira, J.R.M., Peralta, J. and Zoorob, S.E. Optimization of warm mix asphalts using different blends of binders and synthetic paraffin wax contents. *Construction and Building Materials. 24(9): 1621–1631.2010.*

[65] Zhao, W., Xiao, F., Amirkhanian, S.N. and Putman, B.J. Characterization of rutting performance of warm additive modified asphalt mixtures. *Construction and Building Materials. 31(0): 265–272.2012.*

[66] Petit, C., Millien, A., Canestrari, F., Pannunzio, V. and Virgili, A. Experimental study on shear fatigue behavior and stiffness performance of Warm Mix Asphalt by adding synthetic wax. *Construction and Building Materials. 34(0): 537–544.2012.*

[67] Caro, S., Beltrán, D.P., Alvarez, A.E. and Estakhri, C. Analysis of moisture damage susceptibility of warm mix asphalt (WMA) mixtures based on Dynamic Mechanical Analyzer (DMA) testing and a fracture mechanics model. *Construction and Building Materials. 35(0): 460–467.2012.*

[68] Kim, Y.R., Zhang, J. and Ban, H. Moisture damage characterization of warm-mix asphalt mixtures based on laboratory- field evaluation. *Construction and Building Materials. 31(0): 204– 211, 2012.*

[69] Su, K., Maekawa, R. and Hachiya, Y. Laboratory evaluation of WMA mixture for use in airport pavement rehabilitation. *Construction and Building Materials. 23(7): 2709–2714.2009.*

[70] Sharma, A.; Naga, G.R.R.; Kumar, P.; Rai, P. Mix design, development, production and policies of recycled hot mix asphalt: A review. *J. Traffic Transp. Eng. (Engl. Ed.), 9, 765–794.2022.*

[71]Goh, S.W. Development and Improvement of Warm-Mix Asphalt (WMA) Technology. *Thesis Ph.D. Michigan Technological University.2011.*

[72] Goh, S.W. and You, Z. Mechanical Properties of Porous Asphalt Pavement Materials with Warm Mix Asphalt and RAP. *Journal of Transportation Engineering. 1(1): 228.2011.*

[73] Mo, L.T., Huurman, M., Woldekidan, M.F., Wu, S.P. and Molenaar, A.A.A. Investigation into material optimization and development for improved raveling resistant porous asphalt concrete. Materials & Design. 31(7): 3194–3206,.2010.

[74] Daniel, R. Bio asphalt from urban yard waste carbonization *(Ohio: Case Western Reserve University School of Graduate Studies and OhioLINK),2011.*

[75] Williams, R. C., Satrio, J., Rover, M., Brown, R .C. and Tang, S. Transportation Research Board *,88th Annual Meeting, (Washington DC, United States; TRB) 19p,2009.*

[76] Walaa, M., Abbas, B., Siavash, V. and Alexander, A.J. Road Material and Pavement Design. *14 193-213,2013.*

[77] Mohammad,.L N., Elseifi, M., Cooper, S. B. and Challa, H. Laboratory evaluation of asphalt mixtures containing bio-binder technologies (*Sustainable and Efficient Pavement on Airfield and Highway Pavement Conference) chapter 20 pp 128-152. 2013.*

[78] Setiadji, B. UjiProduksi Batch Bioaspalsebagaialternatifpenggantiaspalminyakbumi (*Yogyakarta: Gajah Mada University Electronic Theses and Dissertations),2009.*

[79]Sihombing, A. V. R., Subagio, B. S., Hariyadi, E. S. and Yamin, A.. IOP Conf. Ser.*: Mater. Sci. Eng. 508 012041.2019.*

[80]Sihombing, A. V. R.,Subagio,B. S., Hariyadi, E. S. and Yamin, Bio-asphalt on Asphalt Mixture containing RAP,*Broad Exposure to Science and Technology 2019 (BEST2019.2019.*

[81] Santucci, L.E. Thickness design procedure for asphalt and emulsified asphalt mixes. *In: The 4th international conference on structural design of asphalt pavements. Michigan, USA: Transportation Research board;. p. 424–56.*1977.

[82] Leech, D. Cold bituminous materials for use in the structural layers of roads. *Wokingham, United Kingdom: Transport Research Laboratory; 1994.*

[83] Lanre, O. O. A study on the development of guidelines for the production of bitumen emulsion stabilized raps for roads in the tropics. *In: Department of Civil engineering. Nottingham, United Kingdom: University of Nottingham; 2010.*

[84] Kim, Y., Im, S., Lee, H.D. Impacts of curing time and moisture content on engineering properties of cold in-place recycling mixtures using foamed or emulsified asphalt. *J Mater Civ Eng;23(5):542–53.2011.*

[85] García, A., Lura, P., Jerjen, I. Influence of cement content and environmental humidity on asphalt emulsion and cement composites performance. *Mater Struct;46(8):1275–89. 2013.*

[86] Arabani, M., Kamboozia, N. The linear visco-elastic behavior of asphalt mixture under dynamic loading conditions. *Construct Build Mater;41:594–601.2013.*

[87] Al-Hdabi,.A, Al Nageim, H., Seton, L. Superior cold rolled asphalt mixtures using supplementary cementations materials. *Construct Build Mater;64:95–102.2014.*

[88]Collins, J.H., Bouldi, M.G., Gelles, R., Berker, A. Improved performance of paving asphalts by polymer modification. *J Assoc Asphalt Pav Technol;60. 43-36.1991.*

[89] Socal da silva, L., De Camargo, F., De AlencastroVignol, L., Cardozo NiloSrgioM. Study of rheological properties of pure and polymer modified Brazilian asphalt binders. *J Mater Sci,;39(2). 539-7.2004.*

[90] Jin, H., Gao, G., Zhang, Y., Zhang, Y., Sun, K., Fan, Y. Improved properties of polystyrene-modified asphalt through dynamic vulcanization.*Polym Test;21(6):21–7.2002.*

[91] Garcia-Morales, M., Partal, P., Navarro, F.J., Martinez-Boza, F., Mackley, M. R., Gallegos, C. The rheology of recycled EVA/LDPE modified bitumen. *Rheol Acta;43:482–8.2004.*

[92]Polacco, G., Berlincioni, S., Biondi, D., Stastna, J. Asphalt modification with different polyethylene-based polymers. *Eur Polym;41. 2831-13.2005.*

[93] **Chen, J.S., Liao, M.C., Shiah, M.S.** Asphalt modified by styrene–butadiene–styrene triblock copolymer: morphology and model. *J Mater Civil Eng. ;14(3):224–5, 2002.*

[94]Navarro, F. J., Partal, P., Martinez-Boza, F., Gallegos, C. Thermo-rheological behavior and storage stability of ground tire rubber-modified bitumen. *Fuel;83:2041–8.2004.*

[95] Masson, J., Polomark, G., Collins, P. Glass transitions and amorphous phases in SBS bitumen blends. *Thermochim Acta;436. 96-4.2005.*

[96] Fawcett, A.H. , McNally, T., McNally, G. M., Andrews, F., Clarke, J. Blends of bitumen with polyethylene. *Polymer;40. 6337-12. 1998.*

[97] Hussein, I. A., Iqba, M. H. , Al-Abdul-Wahhab, H. I. Influence of Mw of LDPE and vinyl acetate content of EVA on the rheology of polymer modified asphalt. *RheolActa,45(1):92–112.2005.*

[98] Stangl, K., Jager, A., Lackner, R. The effect of styrene–butadiene–styrene modification on the characteristics and performance of bitumen. *Monatshefte fur Chemie;1389:301–6.2007.*

[99] **Gonzalez, V., Martinez-Boza, F., Navarro, F., Gallegos, C., Perez-Lepe, A., Paez, A.** Thermo mechanical properties of bitumen modified with crumb tire rubber and polymeric additives. *Fuel Process Technol;91(9):1033–6.2010.*

[100] Frantzis, P. Development of crumb rubber reinforced bituminous binder under laboratory conditions. *J Mater Sci;38. 1397-4.2003.*

[101] Yildirim, Y. Polymer modified asphalt binders. *Constr Build Mater;21. 66- 6.2007.*

[102]Munera,J.C., Ossa, E.A.,Polymer modified bitumen: Optimization and selection, *Materials and Design 62 . 91–97.2014.*

[103] Yuliestyan, A, García-Morales, M., Moreno, E., Carrera, V., Partal, P. Assessment of modified lignin cationic emulsifier for bitumen emulsions used in road paving. *Mater Des ,;131:242–51.2017.*

[104] Jamshidi, A., Hamzah, M.O., Kurumisawa, K., Nawa, T., Samali, B. Evaluation of sustainable technologies that upgrade the binder performance grade in asphalt pavement construction. *Mater Des;95:9–20.2016.*

[105] Jr., R., Carrol, Geotechnical Fabrics Report; *Industrial Fabrics Association, International, Roseville, MN, USA, vol. 6, 1998.*

[106] Kumar, R., A Study Review on Geosynthetics use on Flexible Pavement Design.*2005*[Online]. Available: www.ijert.org.

[107]Jewell, D. D. Jewell, R. A., Milligan, G. Interaction between soil and geogrids., *In Polymer grid reinforcement Thomas Telford Publishing., pp. 18–30, 1984.*

[**108] Qian,P. R. L.** Stress Analysis on Triangular-Aperture Geogrid-Reinforced Bases over Weak Subgrade under Cyclic Loading,, Transp. *Res. Rec. J. Transp. Res. Board, vol., pp. 83–91, 2011.*

[109] Giroud, N. L. ., Geotextiles- Reinforced Unpaved Road Design, *Journal of Geotechnical Engineering, 2003.*

[110] HosseinMoayedi,. K. H. Effect of Geo-grid Reinforcement Location in Paved Road Improvement, *EJGE Vol. 14. , 2009.*

[111] G. J. Zhang, Zhang, W., Tang, X., Sun, X., Yang, R., ToAnalytical method for quantifying performance of wicking geosynthetic stabilized roadway., *Geotextiles and Geomembranes., 2022.*

[112] Daniel, E.,**Wegman, P.E. , MohammadrezaSabouri M.,** Optimizing Cold In-Place Recycling (CIR) Applications Through Fracture Energy Performance Testing, *Published by: Minnesota Department of Transportation Research Services & Library.2016.*

[113] Wagoner, M., Buttler, W., Paulino, G., and Blankenship, P. Investigation of the Fracture Resistance of Hot-Mix Asphalt Concrete Using a Disk-Shaped Compact Tension Test,*Transportation Research Board, Washington DC.2005.*

[114] Kim M., Buttler W., Baek J., and Al-Qadi I. Field and Laboratory Evaluation of Fracture Resistance of Illinois Hot-Mix,*Transportation Research Record, Washington DC.2009.*

[115] Li X.J. and Marasteanu M.O. Using Semi Circular Bending Test to Evaluate Low Temperature Fracture Resistance for Asphalt,*Experimental Mechanics, 50 (7): 867-876.2009.*

[116] Elseifi, M., Mohammad, L., Ying, H. and Cooper, S. Modeling and evaluation of the cracking resistance of asphalt mixtures using the semi-circular bending test at intermediate temperature," Road Materials and Pavement Design, 13 (S1): 124-139.2012.