Ilkogretim Online - Elementary Education Online, 2021; Vol 20 (Issue 2): pp. 4009-4021
http://ilkogretim-online.org
doi: 10.17051/ilkonline.2021.02.417

Exploring The Landscape: A Comprehensive Overview Of Materials And Technologies Employed In Road Pavements

Nisha Meena Research Scholar nishameena199695@gmail.com

Abstract

Preserving the lives of global road travelers is significantly influenced by the utilization of well-designed, robust, enduring, and secure roadways. Governments worldwide place considerable emphasis on maintaining roadways, incorporating safety planning into every construction phase, and collaborating effectively with transportation safety stakeholders. The road sector expends extensive efforts to mitigate risks arising from poor pavement conditions, driver behavior, and vehicle maintenance.

Understanding the impact of road construction materials on traffic safety is crucial for the successful implementation of road quality management plans. This study focuses on reviewing and highlighting innovative technologies aimed at enhancing the properties of materials used in transportation structures. The goal is to bolster road strength, durability, and traffic safety, ultimately reducing accidents. Innovations discussed include the use of polymer and geopolymer concrete composites, solar panels, supplementary cementing materials, self-healing substances, shape-memory alloys, and illuminating cement.

Keywords - Road Safety, Road Construction Materials, Transportation Structures, Innovative Technologies.

1 Introduction

Research extensively supports the notion that various factors, including driver training, behavior, vehicle maintenance, road design aspects, and pavement conditions (represented by pavement age, construction materials types, and quality), positively influence accident risk [Takahiro et al., 2018; Wenyu et al., 2018; John, 2017; Ahmed, 2016; Vinayakamurthy, 2017]. While considerable research has delved into the impact of human risk factors on traffic accident frequency, pavement conditions have received comparatively less attention.

Inappropriate pavements, exacerbated by increased traffic volumes and a shorter pavement life, can result in significant and damaging effects on surface degradation caused by extreme weather and heavy traffic. The primary causes of accidents often stem from surface deformations, cracks, and potholes, leading to reduced friction between vehicle tires and the pavement, thereby causing unexpected acceleration [Bella et al., 2012].

Urban road damage can be attributed to various factors, including road flooding due to inadequate stormwater systems, ineffective subsurface drains in the absence of embankments, surface cracks caused by standing trucks allowing water ingress, frequent braking actions causing damage, and wearing coats not designed to withstand heavy tractive forces, especially at junctions. Additionally, non-compliance with specifications and standards related to temperature maintenance during laying and compaction, absence of high-quality bitumen, lack of fuel spillage resistance in bituminous treatment, and the failure of research institutes/academicians to develop specifications tailored to urban problems contribute to road damage.

The objective of this study is to review and highlight technologies aimed at enhancing the properties of materials used in transport structures. These technologies focus on increasing road strength, durability, and traffic safety improvement [Takahiro et al., 2018; Wenyu et al., 2018; John, 2017; Ahmed, 2016; Vinayakamurthy, 2017; Bella et al., 2012].

1.1 Road construction and road pavement

The evolution of road construction methods can be traced back to the first Roman roads around 4,000 BCE, constructed from stone and timber. Over time, the techniques for road construction have undergone significant changes, transitioning from materials like brick and granite blocks to the widespread use of asphalt in modern roads. It has been observed that roads paved with brick and granite blocks reduced the risks of automobile accidents due to the slower driving rates on rough pavements [T.C. Pereira, 2014]. However, contemporary road pavements predominantly utilize asphalt and/or concrete.

The construction of a road involves three main processes: setting out, earthworks, and paving construction [F. Sarie et al., 2015]. The pavement consists of a natural soil sub-grade covered by layers of processed materials. The soil sub-grade's primary function is to distribute applied vehicle loads, and improving the soil, base courses, and surface course materials enhances road strength and durability. Ongoing research focuses on innovations in these materials to construct safer roadways.

Road pavements are broadly classified into flexible and rigid pavements, with further sub-classifications. Rigid pavements typically use Portland cement concrete as the primary structural element, with variations such as plain, lightly reinforced, continuously reinforced, pre-stressed, or fibrous concrete depending on conditions. The type of aggregate used significantly impacts pavement performance and durability. The use of sound materials, such as crushed rock aggregate, results in concrete with higher flexural strength compared to uncrushed aggregates. Additionally, the strength of cement influences the compressive and flexural strength of concrete pavements. Higher strength cement produces concrete with greater compressive and flexural strength when formulated with an identical water-cement ratio [L. Eberhardsteiner, 2019].

Both rigid and flexible pavements may experience different types of failures, including potholes and heavy surface damage [F. Sarie et al., 2015]. Recent advancements in technology and innovative materials aim to prevent road pavement defects. The introduction of new equipment, additives, and improvements in concrete technology enables road engineers to construct high-quality roads [L. Eberhardsteiner, 2019].

2 Pavement stabilization technologies

Pavement stabilisation may be simply defined as the act of changing the inherent qualities of an earthworks material or pavement material by adding a stabilisation agent (e.g., granular material or binder) to fulfil performance expectations during its application. Using the right stabilisation technology to stabilise and recycle materials for pavement construction and maintenance is the most economical way to enhance the long-term performance of intensively used pavements [R. Singh et al., 2018].

2.1 Materials for Soil Stabilization

In general, the stability of the underlying soils affects how well a constructed structure performs over time. Unstable clay soils may lead to serious issues with structures or pavement. Soft soils must first undergo preconditioning in order to increase their mechanical strength before any buildings are built on top of them. As a result, soil stabilisation is often done to boost clay soil's bearing capacity by using stabilising agents (binder materials) to enhance the soil's geotechnical characteristics, including compressibility, strength, permeability, and durability. To improve the geotechnical properties of soil, various stabilisers are tested, such as cement, lime, industrial wastes (like fly ash and rice husk ash), flocculants [J. He et al., 2017], and wastewater sludge and ashes [L. C. d. F. L. Lucenaa et al., 2014; M.A. Shafii et al., 2018].

Furthermore, commercial road design is increasingly using the technology of nano polymer binder for stabilising soil and enhancing its strength. When disseminated in water, nano polymers—fine particles—are significantly more efficient at coating and binding aggregates, including soil particles [M.Z. Hameed et al., 2013]. According to Mirzababaei et al. (2017), there are several advantages to using nano polymers for stabilising soft soils, such as a decreased carbon footprint, road crust, construction costs, maintenance, and the amount of quarry aggregate used in road construction. Additionally, the strength and stability of base and sub-base layers are increased, and construction time is sped up. Soil stabilisation techniques include the use of multiwall carbon nanotube, carbon nanofiber [J. M. A. Alsharef et al., 2016], and metal oxide nanoparticles, such as SiO2, TiO2, and Al2O3 [A. Aroraa et al., 2019; Q. Lv et al., 2018].

2.2 Stabilization of Aggregate Base Materials

Base stabilisation is often used by roadway engineers in the design and/or rehabilitation of pavement constructions. In order to provide a homogenous foundation layer with improved strength, stability, and durability features, the base aggregate materials are modified by adding a stabilising additive. This leads to a long-term increase in the performance of the supported pavement constructions. Re-compaction, drainage, and enhanced grading by introducing missing particle sizes are other stabilisation techniques that may be used [D. Little et al., 2009]. Sludges, polymers, bitumen, cement, and other granular materials are employed as stabilisers.

In order to improve road constructions' operational dependability and delay the emergence of flaws, nepheline sludge was included into road pavements [A. Kvitko et al., 2018]. With the benefit of lowering the pavement's thickness and expense, iron sludge was used as the sub-grade for the roller-compacted concrete pavement [V.D. Bhavsar et al., 2017]. Dry powders of certain polymers and combination blends of polymer additives with lime are among the proprietary solutions being pushed for stabilising base and sub-base courses that have shown encouraging results. Commercial dry powder polymers are produced by thermally attaching an inert fine carrier, such fly ash or silica fume, to a high-grade polymer. They are used to treat low-quality, clayey gravel and sand aggregates with little to no plasticity because they operate to waterproof the aggregate and increase its hydrophobicity. The base course of the road pavement is strengthened and made more flexible by the low concentration of polymer stabilisers, which also keeps the water resistance low [D. Cameron et al., 2016].

In some applications, hydrated lime is combined with dry powder polymers. Without coating the lime with polymer, the lime is introduced to flocculate and prepare clay particles for adherence to the polymer.

2.3 Stabilization Using Bitumen

Bitumen used as an emulsion or foamed substance may stabilise granular pavement materials, previously cement stabilised materials, or recovered asphalt pavement. Bitumen is applied to a combination of recycled pavement materials and the existing layer to create a new base or sub-base layer [G. Jameson et al., 2019]. The aggregate particles are coated with bitumen, which creates an adhesive link between the coated particles and increases their strength. The aggregates with coatings become waterproof. To stabilise the aggregates without affecting the integrity of the matrix, bitumen should be added within a certain amount, however. Since emulsified bitumen doesn't need energy during the stabilisation process, it is not anticipated to age the asphalt.

3 Innovations in road construction

Both the community and the industry profit greatly from innovations in road building. In order to improve the building process, this entails using cutting-edge technology and the best materials [Oad, 2016]. Numerous advancements have been developed for concrete roadways, including high-performance concrete (HPC), self-compacting concrete (SCC), fiber-reinforced concrete (FRC), and Ultra High-performance concrete (UHPC) [Khan & Deulkar, 2017]. The use of nanoparticles as additives in asphalt mixes, such as metallic nanoiron, nanosilica, and nanoclay, has gained attention for the last 20 years [Faruqi et al., 2015; Crucho et al., 2019; Yao & You, 2016]. Additionally, research demonstrates that polysiloxane-modified nanoclay strengthens asphalt and increases its capacity to withstand higher loads at elevated temperatures [Hollaway & Head, 2001].

3.1 Polymers in Road Construction

In road construction, polymers—macromolecular substances, both natural and artificial—that are made up of millions of covalently bound units are essential for stabilising and sealing sub-base, base, and wearing courses. Construction has found success with the use of fiber-reinforced polymer (FRP) composites, which are composed of fibres such as carbon, aramid, and glass embedded in a resin matrix. Because FRP composites are resistant to corrosion and fatigue, they are used in highway and bridge building instead of standard steel bars. However, it is thought that the initial expense of FRP materials and the challenge of self-mixing are drawbacks [Gupta, 2013].

3.1.1 Asphalt Pavement with Polymers

Although it has been a mainstay in road building, asphalt, a petroleum-based binding agent, has temperature limitations. Polymeric modifiers, particularly those of the styrene butadiene (SB) type, have been shown to be useful in improving the characteristics of bituminous concrete mixtures. By lowering moisture absorption and porosity, waste SB rubber from tyres has been recycled and utilised to enhance the functionality, dependability, and longevity of both flexible and rigid road pavements. The rheological properties of asphalt binders have been shown to improve with the incorporation of different waste plastics, such as recycled polystyrene and high-density polyethylene [Sabadra, 2017; Asmaela & Waheed, 2018; Pardeshi & Raut, 2018; Brasileiro et al., 2019; Baker et al., 2016; Caseyac et al., 2008; Khan et al., 2016; Ciesin´ska, 2017; Wiesława, 2015; White & Reid, 2018].

3.1.2 Utilization of Geopolymers

For more sustainable road construction materials, geopolymer, an inorganic alumina silicate binder system, has gained attention. Geopolymer concrete, based on industrial wastes and recycled materials like fly ash, slag, and silica fume, serves as an alternative to conventional Portland cement. Geopolymers are used in various road construction applications, such as stabilizing soil, pavement base materials, and rapid road repair of concrete infrastructures. They contribute to reduced drying shrinkage, improved strength, and enhanced mechanical properties in pavements [Wattanachai & Suwan, 2017; Gargav & Chauhan, 2016; Wong et al., 2019; Teerawattanasuk & Voottipruex, 2019; Hawa et al., 2013; Hoy et al., 2016].

3.1.3 Bioasphalt in Road Construction

With the rising cost of petroleum-based asphalt, alternative binders such as bioasphalt have gained popularity. Bioasphalt, derived from plants and trees, offers economic, social, and environmental benefits. Biopolymers, produced by living organisms, serve as alternatives to petroleum-based polymers. Various biomaterials, including waste cooking oil, coconut shell bioasphalt, and bio-oil modifiers, have been explored to improve the rheological properties of asphalt binders. However, challenges remain, as some biomaterials may impact the high-temperature rheological properties of modified asphalt; Djumari et al., 2017; Abd El-latief, 2018; Ji et al., 2016; Sihombing et al., 2019; Wang et al., 2019; Kumar et al., 2018; v. Vliet et al., 2016; Zhang et al., 2019; De Maeijer et al., 2019; Sasidharan et al., 2019].

3.1.4 Plastic Road Technology

While the use of waste plastics in road construction is relatively new, the concept of plastic road technology, where roads are constructed entirely from recycled plastics, has gained global attention. Countries like India, Netherlands, Scotland, and the U.S. are leading this innovation. Plastic roads, prefabricated from recycled plastics using a polymer-based glue and tar mixture, offer advantages such as lighter weight, modular design, faster construction, and efficient maintenance. The hollow space beneath the surface can be utilized for water storage, cable and pipe passage, electric vehicle charging, and sensor installations. Despite these advantages, the long-term outcomes of plastic road technology are still unclear [Sasidharan et al., 2019].

3.2 Solar energy

Solar energy is a sustainable and globally available thermal source. Road pavements, being expansive surfaces, act as substantial solar thermal collectors, absorbing solar radiation throughout the day. This collected energy can be harnessed by circulating fluid through the pavement. This technology is widely implemented in various countries to regulate the temperature of road pavements during winter and summer [J.B. Sheeba, A.K. Rohini, J. Energy 2014 (2014)].

On the other hand, solar roads represent an emerging technology wherein roads are equipped with solar panels, specifically Silicon resin-strengthened Photo-Voltaic (PV) panels. These panels, embedded in the pavement and shielded by a layer of transparent concrete, utilize the sunlight absorbed by silicon to generate electricity. LED lights incorporated into the panels eliminate the need for paint in creating road markings and signage. Solar roads have the capacity to power their own traffic-light systems, video surveillance, and street-lighting. They are designed with heating elements to prevent snow and ice accumulation and can potentially recharge electric vehicles through induction as they drive along the road. This innovation aims to encourage the use of environmentally friendly electric cars. However, challenges faced by solar roads include the performance of PV systems, which can be significantly affected by internal and external factors, including shading. Increased shading on a photovoltaic module surface can result in a notable reduction in power [M.E. Meral, F. Diner, Renew. Sustain. Energy Rev. 15 (2011) 2176–2184]. Additionally, issues such as improper angling of panels, costly maintenance, and the absence of a cost-effective manufacturing method that ensures durability under daily driving strains pose hurdles. Nevertheless, if solar roads were to replace conventional paved surfaces entirely, they could contribute significantly to the country's electricity needs.

3.3 Sustainable Concrete Using Supplementary Cementing Materials (SCMs)

To address the depletion of natural resources and reduce greenhouse gas emissions, alternative materials like manufactured sand and aggregates from iron, zinc, steel, and copper slag have been proposed. Supplementary Cementing Materials (SCMs) such as fly ash, ground granulated blast-furnace slag (GGBS), silica fume, rice husk ash, and natural pozzolans have been tested and applied individually or in various combinations with Portland cement. Incorporating SCMs in concrete mixtures has shown potential in producing more economical concrete. The resulting mixtures exhibit reduced heat of hydration and permeability, increased strength, and improved chemical stability [A. Tabakovic, E. Schlangen, In book: Advances in Polymer Science Chapter: Self-Healing Technology for Asphalt Pavementsr, D. Hager, U. S. Schubert, S. van der Zwaag, Springer, Berlin Heidelberg edited by M, 2015].

3.4 Self-Healing Pavement

Self-healing technology enables material systems, especially asphalt pavements, to heal after damage, reducing the level of damage and extending the functionality and lifetime of the damaged part. Asphalt pavement inherently possesses autogenously healing properties. During rest periods, the pavement can restore its stiffness and strength by closing micro-cracks formed under traffic loads. However, improvements in self-healing performance can be achieved by introducing modifiers and additives to the asphalt mix. Three main self-healing technologies are nanoparticles (NPs), induction heating, and rejuvenation [Liu, R., Zhibin, Z. & Rui, Z., et al, Nanotechnology synthesis study: Research Report, Texas Department of Transportation (2007)].

Nanoparticles, including nanoclays, are added to enhance aging, rheological, and thermal properties. Induction heating involves using electrically conductive fibers and fillers (carbon fibers, graphite, steel fibers, steel wool) and conductive polymers (like polyaniline) to improve self-healing in asphalt pavements. Rejuvenation is achieved by using a rejuvenating agent, such as a cationic emulsion, to reduce the stiffness of oxidized asphalt binder and extend pavement life by adjusting asphalt mix properties. Additionally, self-healing polymers that automatically heal cracks have been developed, utilizing microencapsulated agents and catalytic chemical triggers within a polymer matrix. These materials release healing agents into crack planes through capillary action, with polymerization triggered upon contact with embedded catalysts, bonding the crack faces [J.Y. Wang, H. Soens, W. Verstraete, D. BelieN.,, Cem. Concr. Res. 56 (2014) 139–152].

Another approach involves the use of living bacteria spores and calcium lactate in self-contained pods. When these pods come into contact with water, they produce calcite, filling damaged areas of the concrete and making it stronger. Despite the potential cost savings of up to 50% in concrete's lifetime cost, further research is needed to address issues related to microbial survival rates and voids produced by microbial death [L.C. Wang, K. Zou, J. Chinese Ceramic Soc. 47 (2019) 1652–1662]. Smart concrete, incorporating living bacteria, is still undergoing laboratory testing to determine the sustainability of the bacteria. Researchers are optimistic about its future introduction to the construction industry.

3.5 Shape Memory Alloys

Shape-memory alloys (SMAs) represent another category of smart materials that can convert thermal energy directly into mechanical work. SMAs exhibit the shape-memory effect and super-elasticity. The shape-memory effect allows alloys to revert to their initial shape upon heating until they reach their phase transformation temperature. Super-elasticity refers to the property of alloys to exhibit large recoverable strain. SMAs can function as passive, semi-active, or active components to reduce damage caused by environmental impacts or earthquakes. They have found applications in counteracting problems of uneven joints causing fatigue cracking and tensile damage in pavements. SMAs can perform phase transformations based on temperature and stress conditions, providing a promising solution to temperature-induced stress and cracking issues in concrete structures [W.D. Callister Jr. D. G., Rethwisch. Materials Science and Engineering: An Introduction. John Wiley and Sons 8th ed., 2009].

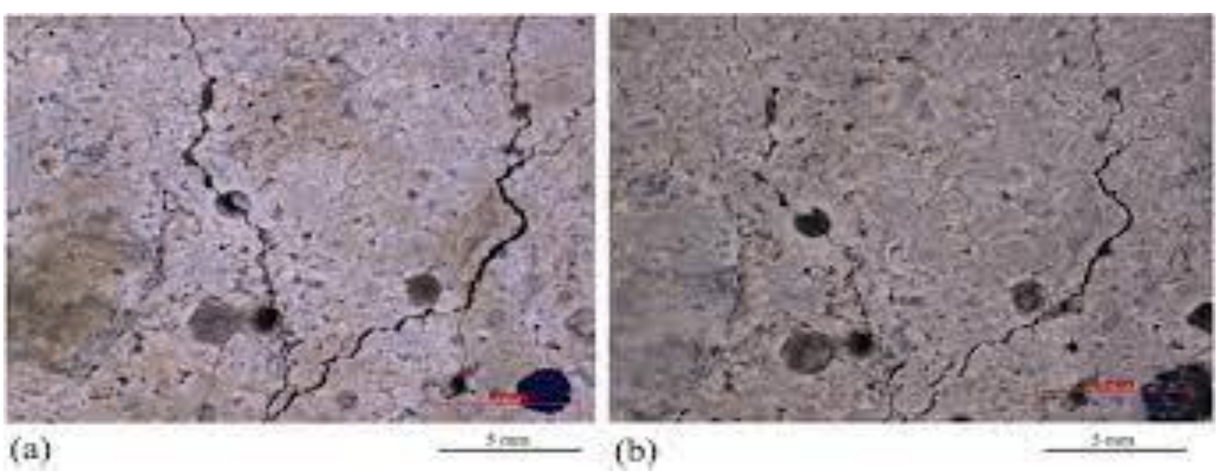

Figure 1

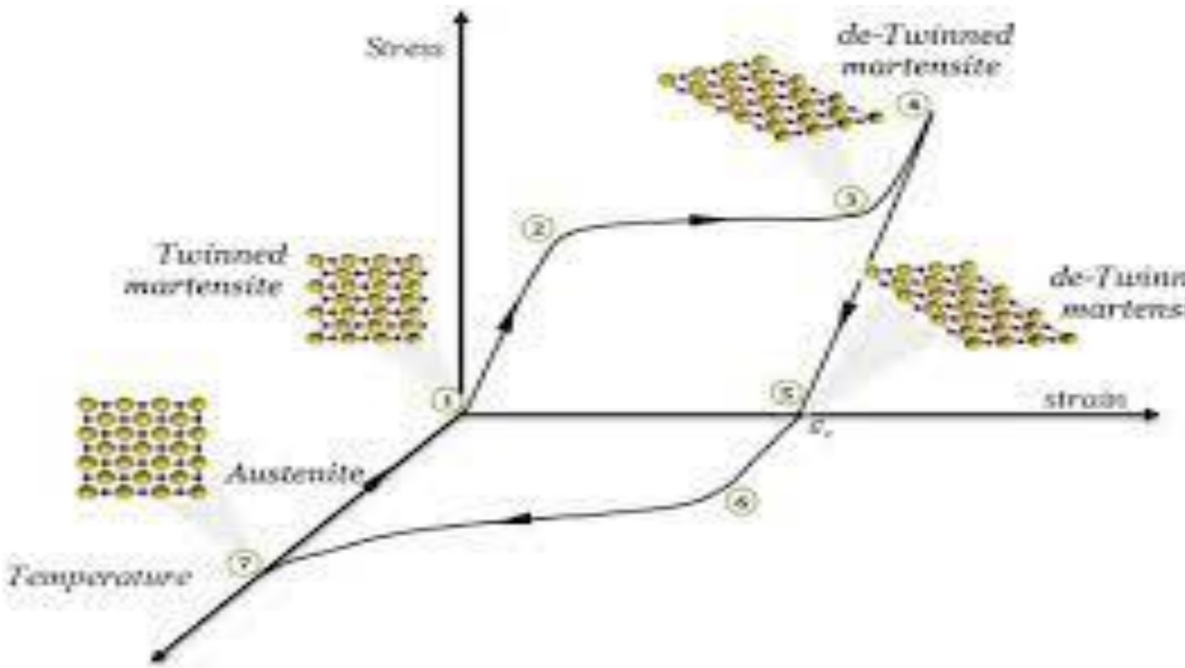

Figure 2

The production of memory-steel, an iron-based shape-memory alloy (SMA) designed for civil engineering applications, is now a widespread industrial practice. This alloy is utilized as a pre-stress material for reinforced concrete. When produced in strips and bars, it can be affixed to buildings to enhance load-bearing capacity. The SMA steel bars, once in place, can be deformed and pre-stressed. They have proven successful as external end-fixed reinforcements for new concrete structures or retrofitted to existing ones, requiring less invasive work than traditionally needed [W.-S. Chang, Y. Araki, Civil Eng. Proc. Inst. Civ. Eng. 169 (2016) 87–95].

These SMAs can also be employed to manufacture smart strands, which are actuators designed to handle different settlement, time, and temperature-dependent effects. They can be activated by external heating or internal stress changes. These strands are mechanically deformed and then embedded in concrete structures like bridges and highways. The pre-stressing and self-repair effects can be activated as needed throughout the structure's life. The key advantage of using SMAs in concrete structures is the reduction in repair costs, as the shape-memory alloy exhibits super-elasticity, enabling structures to possess self-centering capacity [Companies like Shape Change Technologies LLC (www.shapechange.com) produce products of SMAs].

3.6 Illuminating Cement (Glow-in-the-dark Concrete) Solar-Powered Cement

The field of illuminating cement, or glow-in-the-dark concrete, is relatively new, with limited research available. Despite this, applications of luminous concrete in coating buildings and highways show promise in reducing the need for energy-intensive road and building lighting. The credit for inventing glow-in-the-dark cement goes to Mexican scientist Jose Carlos Rubio Avalos, who created a material that traps light during the day and releases it at night. This technology involves using phosphorescent materials mixed with cement to create surfaces that can illuminate walkways, buildings, and roadways at night. The cement absorbs sunlight, stores energy, and excites electrons during the day. At night, the relaxed electrons return to their original state, emitting light without the need for electricity [S. Hesami, V. Sadeghi, Int. J. Pavement Res. Technol. 8 (2015) 251–258].

This breakthrough technology allows drivers to navigate roads without relying on traffic lights or vehicle headlights. The incorporation of photoactive materials into cement allows it to absorb and emit light, even on cloudy days. The glowing surfaces have the potential to save on street lighting costs, and the manufacturing process is environmentally friendly, releasing only water vapor and avoiding the formation of toxic by-products. While the cost of producing illuminating cement has been demonstrated to be around $60–70 for a one square meter piece, its impracticality and expense stem from the high quantity of Strontium aluminate powder needed to produce a usable glow [Luminescent concrete has other limiting factors, including the opacity of traditional concrete, hindering the passage of light. However, ongoing research aims to address this by incorporating clear aggregates and binding agents to alter crystalline structures formed during concrete curing].

4 Conclusion

To sum it up, the materials chosen for road construction play a crucial role in ensuring transportation safety. Well-designed roadways, coupled with appropriate construction materials, contribute to an extended service life. The longevity of materials used in road construction is contingent upon various factors, making the careful selection of suitable materials a vital aspect of road construction projects. Recent advancements in road construction involve the utilization of innovative technologies and materials, such as developed stabilizing agents added to soil, base, and asphalt pavement materials to mitigate road pavement defects. The incorporation of new equipment and advanced technologies, including but not limited to novel fiber-reinforced polymers, geopolymers, nanoparticles, self-healing materials, shape memory alloys, and photoactive materials, along with improvements in concrete technology, has facilitated the construction of high-quality roads. These developments contribute not only to road quality but also enhance overall road safety.

References

1. A. Aroraa, B. Singhb, P. Kaurc, Mater. Today 17 (2019) 124–130.

2. A. Kvitko, V. Shendrik, I. Mukharryamov, Transp. Res. Procedia 36 (2018) 404– 410.
3. A. Tabakovic, E. Schlangen, In book: Advances in Polymer Science Chapter: Self-Healing Technology for Asphalt Pavementsr, D. Hager, U. S. Schubert, S. van der Zwaag, Springer, Berlin Heidelberg edited by M, 2015.
4. A.A. Firoozi, C.G. Olgun, M.S. Baghini, Int. J. Geo-Eng. 8 (2017) 26.
5. B.M. Pardeshi, S.A. Raut, Int. J. Chem. Phys. Sci. 7 (2018) 37–41
6. C.S. Cai, W. Wu, S. Chen, G. Voyiadjis, Louisiana Transport. Res. Center (2003) 1–14.
7. D. Cameron, C. Hopkins, M. Rahman, Procedia Eng. 143 (2016) 26–33.
8. D. Caseyac, C. McNallyad, A. Gibneya, M.D. Gilchris, Res. Conserv. Recycl. 52 (2008) 1167–1174.
9. D. Little, S. Nair, National cooperative highway research program (NCHRP), Transport. Res. Board 144 (2009) 1–67.
10. D.Basu, A.J. Puppala, Chittoori B. Proceedings of the 18th conference on SMGE, Paris 2013, Volume 1, 1155-1162. C. Hopkins, D. Cameron, M. Rahman, A. Rabbi, ARRB Conference 27th, Melbourne, Victoria, Australia, 2016.
11. D.E. Wegman M. Sabouri J. Korzilius R. Kuehl B. Intertec LRRB Report 2017RIC02 December (2017).
12. E. Ahmed F. PhD diss., University of Akron, 2016.
13. E. Remišová, M. Decky´ , M. Mikolaš, M. Hájek, L. Kovalcˇík, M. Mecˇár, IOP Conf. Series: Earth Environ. Sci. 44 (2016) 022016.
14. F. Bella, A. Calvi, F. D'Amico, Procedia Soc. Behav. Sci. 53 (2012) 943–952.
15. F. Sarie, M. Bisri, A. Wicaksono, R. Effendi, IOSR J. Environ. Sci. Toxicol. FoodTechnol. 9 (2015) 53–59.
16. G. Jameson, G. Hennessy, Guide to Pavement Technology Part 4D: Stabilised Materials, Austroads, Sydney, 2019.
17. G. White, G. Reid, 8th Symposium on Pavement Surface Characteristics, Brisbane, Queensland, 2018.
18. G.F. John, IATSS Res. 40 (2017) 72–75.
19. H. Yao, Z. You, J. Nanomater. 2016 (2016).
20. H.E. Donn, TR News 205 (1999) 10–15.
21. I.M. Khan, S. Kabir, M.A. Alhussain, F.F. Almansoor, Int. Conf. Sustain. Des. Eng. Construct. 145 (2016) 1557–1564.
22. J. He, J. Chu, S.K. Tan, T.T. Vu, K.P. Lam, J. Marine Geores. Geotechnol. 35 (2017)593–602.
23. J. M. A. Alsharef, M. R. Taha, A. A. Firoozi, and P. Govindasamy. 2016 (2016) |Article ID 5060531
24. J. Malaiskiene, G. Skripkiunas, M. Vaiciene, E. Karpova, IOP Conf. Series: Mater.Sci. Eng. 251 (2017) 012025.
25. L. Brasileiro, F. Moreno-Navarro, R. Tauste-Martínez, J. Matos, M.d.C. RubioGámez, SustaSinability 11 (2019) 646.

26. L. C. d. F. L. Lucenaa, J. F. T. Juca, J. B. Soaresc, P. G. T. M. Filho. Transport and Environment, 33 (2014) 210-219.
27. L. Eberhardsteiner, J. Road Mater. Pavem. Des. 20 (2019) 244–258.
28. L.C. Hollaway, P.R. Head, Elsevier Science, Ltd. (2001).
29. Liu, R., Zhibin, Z. & Rui, Z., et al, Nanotechnology synthesis study: Research Report, Texas Department of Transportation (2007).
30. M. Dolce, D. Cardone and R. Marnetto, in Smart Structures and Materials, International Society for Optics and Photonics 4330 (2001) 249. Trinastic J., Scitable, June 3 (2016).
31. M. Mirzababaei, A. Arulrajah, M. Ouston, Procedia Eng. 189 (2017) 25–32.
32. M. Sasidharan, E. Torbaghan, M.P.N. Burrow, K4D Helpdesk Report, Institute of Development Studies, Brighton, UK, 2019.
33. M. Vinayakamurthy, Master thesis, Arizona State, USA, 2017.
34. M.A. Shafii, N.M. Noh, ARPN J. Eng. Appl. Sci. 13 (2018) 8280–8284.
35. M.B. Baker, R. Abendeh, Z. Abu-Salem, T. Khedaywi, IJAES 11 (1) (2016) 183–192.
36. M.Z. Hameed, M.R. Taha, Aust. J. Basic Appl. Sci. 7 (2013) 576–581.
37. N.M. Asmaela, M.Q. Waheed, Merican Scientific Research Journal for Engineering, Technology, and Sciences, (Online) (2018) 38–43.
38. N.X. Rojas, J. Mennis, Int. J. Environ. Res. Public Health 16 (2019) 3704.
39. P. Wattanachai and T. Suwan, IOP Conference Series: The 4th International Conference on Manufacturing and Industrial Technologies 27– 29 May 2017, Lisbon, Portugal.
40. P.K. Gupta, Int. J. Adv. Struct. Eng. 5 (2013) 19.
41. P.K. Oad MSc thesis, Queensland University of Technology, 2016. S. Khan, V. Deulkar, Int. J. Latest Trends Eng. Technol. 7 (2017) 130–136. M. Faruqi, L. Castillo, J. Sai, J. Civ. Eng. Res. 5 (2015) 21–27. J. Crucho, L. Picado-Santos, J. Neves and S. Capitão 9 (2019) 3657.
42. P.K.De Maeijer, H. Soenen, W. Van den bergh, J. Blom, G. Jacobs, J. Stoop. Infrastructures, 4(2019) 3.
43. Q. Lv, C. Chang, B. Zhao, Soil Mech. Found. Eng. 54 (2018) 409–413.
44. Q. Wenyu, X. Liu, Z. Kong, Open J. Soc. Sci. 6 (2018) 90–96.
45. R. A. E. Abd El-latief, Modified Asphalt, J.L. Rivera-Armenta and B.A. SalazarCruz, IntechOpen (2018) DOI: 10.5772/intechopen.76832.
46. R. Bednar, S. Merritt, ENGR-090 project, Swarthmore College, Department of Engineering, 2018
47. R. Singh, P. Srivastava, P. Singh, A.K. Sharma, H. Singh, A.S. Raghubanshi, EcolIndic 105 (2018) 505–515.
48. S. Djumari, M.A. DaimYami, M.F. Nasution, A. Setyawan, Procedia Eng. 171 (2017) 1413–1420.
49. S. Hesami, V. Sadeghi, Int. J. Pavement Res. Technol. 8 (2015) 251–258.
50. S. Richard, J. Macmillan, Int. High. Educ. (1988).

51. S.N.S. Al-Humairi Recent Advancements in the Metallurgical Engineering and Electrodeposition 2019 IntechOpen.
52. T. Takahiro, C. Fernando, T. Yoshii, H. Shirayanagi, Transport. Res. Procedia 34 (2018) 211–218.
53. T.C. Pereira, MSc thesis in civil engineering, Faculty of Science and TechnologyUniversity of Lisbon (2014).
54. V. Sabadra, Int. Res. J. Eng. Technol. 04 (2017) 799–801.
55. V.D. Bhavsar, D. Vaghela, IJARIIE 3 (2017) 1175–1178.
56. W. Ciesin´ ska, J. Therm. Anal. Calorim. 130 (2017) 187–195. W. Wiesława, Polimery 60 (2015) 144.6.
57. W.D. Callister Jr. D. G., Rethwisch. Materials Science and Engineering: An Introduction. John Wiley and Sons 8th ed., 2009.
58. W.-S. Chang, Y. Araki, Civil Eng. Proc. Inst. Civ. Eng. 169 (2016) 87–95.
59. Y. Gao, B. He, M. Xiao, Z. Fang, K. Dai, Constr. Build. Mater. 165 (20) (2018) 548–559.
60. Y. Zhang, X. Liu, P. Apostolidis, W. Gard, M. Ven, S. Erkens, R. Jing, Mater. 1 (2019) 4176.
61. Z. Bredenkamp, Doctoral dissertation, Stellenbosch University, Stellenbosch, 2018.