CONSTRUCTION
VOL. XX, ISSUE XX, XXX – XXX
DOI: https://doi.org/10.15282/construction.v5i2.12991

UNIVERSITI MALAYSIA PAHANG

ORIGINAL ARTICLE

A Review on the Modification of Cold-Mix Asphalt for Pavement Construction

A.A.Al-Attab[1], K.A.Masri[1,*] and Juhyuk Moon[2]

[1]Faculty of Civil Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, 26300 Gambang, Pahang, Malaysia
[2]Department of Civil and Environmental Engineering. Seoul National University, South Korea

ABSTRACT –Cold mix asphalt (CMA) reduces energy input and greenhouse gas emissions through production and placement at ambient temperatures. The chief limitations entail high air-void content, long curing time, and initial low strength. This systematic review aggregates recent experimental work related to additives targeting these disadvantages. Geopolymer additives develop hardened structures improving Marshall stability and, when used at optimal asphalt-geopolymer ratio, allow short curing times. Industrial by-product fillers, i.e., paper sludge ash and cement kiln dust, increase stiffness and reduce cure times and offer more environmentally friendly substitutes for conventional fillers. Nanomaterials have been widely studied in hot-mix asphalt and binder contexts; they can modify viscosity and increase rut resistance but at the potential cost of sacrificing low-temperature ductility. Very few studies have directly applied nanoparticles to CMA in peer-reviewed research, and this represents an important gap in research findings. Among CMA studies investigated here, overall CMA performance was generally boosted in terms of resilient modulus, resilient and permanent deformation, and moisture resistance; excessive stiffening could, however, undermine fatigue resistance. The review highlights important research questions related to long-term durability, life-cycle performance, and dosage optimization and highlights priorities for future CMA research.

ARTICLE HISTORY
Received: xxxx
Revised: xxxx
Accepted: xxxx

KEYWORDS
Cold-mix asphalt (CMA)
Geopolymer additives
Industrial by-product fillers
Fiber and polymer modifiers
Performance testing
Morphological characterization

INTRODUCTION

Cold Mix Asphalt (CMA) represents a lightweight pavement, environmentally-friendly material as it can be made, mixed, and applied without heating and limits energy consumption and emissions versus Hot Mix Asphalt (HMA) [1, 2]. CMA uses either a emulsified or cutback, as opposed to HMA which is produced with heat. CMA can be produced, and used in challenging or remote regions, and has the potential for use during adverse weather (Mohammadian et al., 2020). In addition, CMA can offer advantages over HMA regarding their ability to be dissolved, if an accidental cracking occurs. Furthermore, Rigidity (stiffness modulus) is lower in emulsion-only CMA (No-CEMA) than in cement-modified CMA because cement hydration forms a composite network that raises stiffness; even so, both cold mixes generally trail HMA in stiffness, especially at early ages , "traditional" CMA still presents challenges including long curing time, lower initial strength, and unstable to moisture damage, which affects acceptance rates for high-volume traffic pavements [3, 4]. Some of these properties can easily be modified through several research initiatives, such as; introducing cement to speed up curing, using crumb rubber to incorporate flexibility from waste tires, and polymers to improve viscoelastic properties, nano-materials to further improve durability and environmental impact [5-9]. Cold paving asphalt mixtures are largely used as cold patching materials in the field of pavement maintenance engineering and are typically made up of aggregates bound by emulsified or solvent-based binders [10, 11]. For improved workability and storage capacity at ambient temperatures, diluents like diesel or kerosene are often added [11]. A wide range of modifiers has been highlighted for solving the shortcomings of poor early strength and sensitivity to moisture with cold mix asphalt (CMA). Geopolymer additives form rigid networks that improve Marshall stability when used in an ideal asphalt to geopolymer proportion of 4:3 [12], while waste-derived fillers like paper sludge ash and cement kiln dust make the mix stiffer and with lower curing times [13]. Blends of cement, fly ash, and GGBS enhance indirect tensile workability by about 20% [14]. Basalt fiber reinforcement improves initial, molding, and immersion strengths along with residual stability and freeze-thaw resistance [15]. Polyurethane binders produce cold recycled mixtures with outstanding adhesion and enhanced freeze-thaw characteristics when reclaimed asphalt pavement accounts for up to 40% of the mix [16]. Styrene-ethylene-butadiene-styrene (SEBS) polymer in conjunction with diesel increases residual stability and freeze-thaw ratios while maintaining two months of storage stability as the minimum [10]. Water-based epoxy asphalt mix emulsions exhibit more than 98 times higher dynamic stability and reduced rut depths by more than 11 times compared to traditional emulsified mixes [17]. A waste $Ca(OH)_2$ solution-based geopolymer cold asphalt emulsion mixture mixed with GGBFS and calcium carbide residue achieves about 13 times the indirect tensile stiffness modulus of a control mixture after three days of

*CORRESPONDING AUTHOR | K.A.Masri | ✉ khairilazman@umpsa.edu.my

curing and significantly reduces rutting [18]. These different modifications indicate the wide range of the research dedicated to the development of the performance and life of CMA.

METHODOLOGY

The review adhered to a systematic methodical approach. Open-access databases (MDPI, Frontiers, De Gruyter and PMC) were searched in September 2025 using the search parameters (cold mix asphalt, nanoparticles, geopolymer, titanium dioxide, waste filler and modification). Articles were included only if they (a) examined CMA or emulsified asphalt mixtures made at low temperature, (b) used modifiers like nanoparticles, geopolymer additives or industrial by-product fillers, and (c) provided experimental or field information. Eleven articles met the inclusion criteria. Information regarding types of materials, dosage, mechanical properties and performance tests, and microstructural characterisation was extracted, and quality of evidence was assessed. In-text citations are inserted throughout, and a numbered reference list is included in the end. We used PRISMA-2020 reporting of information sources and study selection guidance. To aim the pavement and asphalt literature directly, TRID (Transportation Research International Documentation), the key transport index combining TRIS and ITRD and spanning journals, Transportation Research Board proceedings, and technical reports was given top priority, followed by ScienceDirect for publisher-hosted full-text from core civil/transport journals. Backward and forward citation chasing (snowballing) was also utilized for the minimum probable number of studies lost. PRISMA selection table (Table 1) records counts at each stage.

Table 1. Study selection (PRISMA-2020)

Stage	Count (n)	Primary reasons for exclusion (if applicable)
Records identified via databases: TRID	4	—
Records identified via databases: ScienceDirect	12	—
Additional records via other sources (snowballing/publishers)	0	—
Duplicates removed	2	TRID↔ScienceDirect [8, 9]
Records after deduplication	14	—
Titles/abstracts screened	14	—
Titles/abstracts excluded	3	Review (n=1); Binder-only (n=1); Not CMA (n=1)
Full-text articles assessed for eligibility	11	—

GEOPOLYMER AND MINERAL ADDITIVES

Geopolymers develop when aluminosilicate precursors (fly ash or slag) react with alkaline activators to form a three-dimensional network that cures at room temperature. In a cold mix study, [19] prepared a cold mix asphalt (CMA) with a geopolymer additive and assessed the macro strength of the CMA with Marshall stability tests. As shown in figure 1, It was shown that stability increased with increasing geopolymer content with an optimum mass ratio of base asphalt and geopolymer at 4:3. Beyond this mass ratio, stability started to decline [20]. While strength develops rapidly in the first three days of curing, it then levels off. From fluorescence microscopy, it was found that the geopolymer formed a bond between the asphalt and the aggregate surfaces forming a continuous rigid network to confine the aggregates under vertical loads [20]. These results show that geopolymer additives can mitigate CMA's low early strength by improving adherence and introducing a rigid binder matrix.

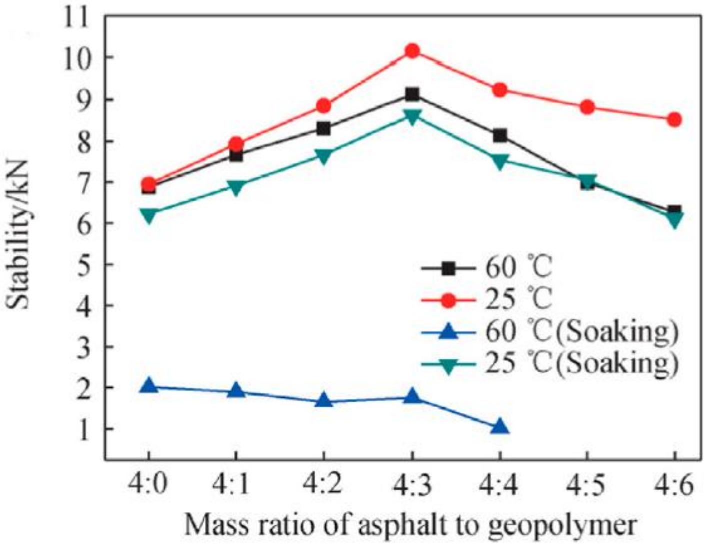

Figure 1. Stability and Mass rastio of asphalt [1]

In attempts to avoid the high costs and greenhouse gas emissions of Portland cement, researchers have explored the use of waste products as potential substitute fillers. Dulai et al. carried out replacements of 0–6% paper sludge ash and 0–4% cement kiln dust for the mineral filler of CMA, which resulted in significant improvements in the stiffness and strength of the mixtures [21]. The pozzolanic characteristics of paper sludge ash enabled the development of internal bonds, while the cement kiln dust acted as an activator to shorten curing times. Further research used a blend consisting of 2% cement and 1% fly ash and 1% GGBS, which yielded a boost in indirect tensile strength by around 20% compared to the use of cement in isolation, thus proving that blended mineral fillers can improve early strength and water resistance [21].

Nano-material modifications

Nanomaterials, defined as particles with at least one dimension between 1 and 100 nanometers, have a high specific surface area and increased reactivity. The interaction of nanomaterials with bitumen molecules can contribute to increased viscosity, micro void fill, and the addition of photocatalytic behavior. [20] offered a thorough classification of nanomaterials into zero-dimensional, one-dimensional, and two-dimensional particles and mentioned that their interaction with asphalt binders causes increased viscosity and stiffness, which can improve resistance to high-temperature rutting as well as low-temperature cracking [20]. This classification is with respect to asphalt binder and hot mix asphalt research, not cold mix asphalt (CMA), and is included here only to situate the category of nanomaterials in question that may be relevant to CMA. To date, most of the literature with respect to nano TiO_2, nano silica, or nano alumina has been focused on hot mix asphalt or binder rheology; however, no peer-reviewed work has been uncovered that utilizes nanoparticles in cold mix asphalt mixtures. Therefore, it is not possible to offer a summary of dosage-dependent performance results for nanomaterial-modified CMA. Encouraging results gained in hot mix tests suggest the potential for nanomaterials to improve the characteristics of CMA; however, more research is needed to confirm their effectiveness in cold mix applications and address issues of compatibility, dispersion, and cot [21].

Morphological characterisation

Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDX), X-ray Diffraction (XRD), and Fourier Transform Infrared Spectroscopy (FTIR) are common analytical tools used to examine the influence of modifiers on the microstructural properties of cold mix asphalt. [19] used SEM to analyze and compare the characteristics of paper sludge ash (PSA), cement kiln dust (CKD), and traditional limestone mineral filler (CLMF) in a cold bituminous emulsion mix. The PSA particles had a porous and irregular surface, whereas those of CKD were flocculent agglomerates, and CLMF were more solid and angular grains. Figure 2 shows these SEM micrographs representing the relatively more open structures of PSA and CKD compared to CLMF. Such resulting morphological differences suggest that PSA and CKD have a higher tendency to interact with the asphalt emulsion compared to CLMF, which acts mostly as an inert filler.

In a geopolymer cold asphalt emulsion mixture, [24] reported that the alkaline $Ca(OH)_2$ solution dissolved silica and alumina from ground granulated blast furnace slag (GGBFS) and calcium carbide residue (CCR), forming calcium silicate hydrate (C–S–H) and calcium aluminosilicate–hydrate (C–A–S–H) gels that filled voids and bonded aggregates. SEM images showed a dense cementitious matrix without residual CCR shells; EDX spectra revealed calcium, aluminium and silicon in the binder, and XRD/FTIR confirmed consumption of $Ca(OH)_2$ and formation of geopolymer gels. These microstructural observations explain the high stiffness modulus and rut resistance reported for geopolymer modified CMA.

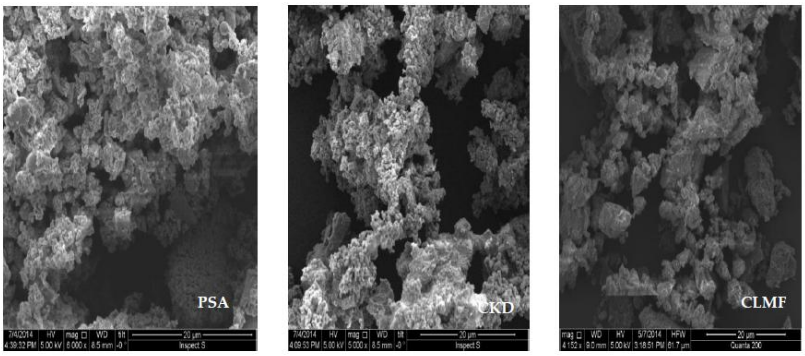

Figure 2. SEM view of filler particles [2]

Performance Testing of Modified CMA

Lab tests are performed to examine the performance of modified Cold Mix Asphalt (CMA) mixtures under different loading and environmental conditions [19]. The addition of geopolymer additives increases the Marshall stability of CMA to a maximum at the optimal mass ratio of 4:3 for asphalt to geopolymer, followed by a reduction in stability at higher dosages [21]. Replacement with paper sludge ash (PSA) and cement kiln dust (CKD) in place of mineral filler improved the mixture's stiffness and strength, along with a decrease in curing time [21], whereas blending of cement with fly ash and ground granulated blast furnace slag (GGBFS) brought about the indirect tensile strength by almost 20% [17]. Basalt fiber reinforced-CMA showed remarkable strength improvement with initial strength, molding strength, and immersion strength being 2.42 kN, 4.87 kN, and 6.79 kN, respectively; residual stability reached 92.8%, the freeze-thaw splitting ratio was 82.05%, and the mixture showed good workability after storage for a month (Sun et al., 2020). Polyurethane cold recycled mixtures exhibited excellent interfacial adhesion between the reclaimed asphalt pavement (RAP) and the polyurethane binder; the maximum splitting strength was found at a glue to stone ratio of 9%, though excessive RAP content reduced high and low-temperature stability, but improved freeze-thaw resistance at RAP content levels below 40% [17]. A geopolymer cold asphalt emulsion mixture (GCAE) using waste alkaline $Ca(OH)_2$ solution, GGBFS and calcium carbide residue (CCR) showed exceptional early age properties: the indirect tensile stiffness modulus (ITSM) increased by approximately 13 times relative to a traditional limestone filler mix after 3 days of curing [18]; rut depths were 5.5 times shallower than the reference mix [6] and the stiffness modulus ratio (SMR) improved by about 40 % [20]. Collectively, these tests indicate that properly chosen modifiers geopolymers, waste fillers, fibers and polyurethane binders—can enhance early strength, rutting resistance, moisture durability and freeze–thaw performance of CMA. Nonetheless, excessive stiffening may reduce cracking resistance, underscoring the need for balanced mix designs.

Polymer-modified cold asphalt mixtures (CAMs) form a key area of research in the field of materials science [14, 15]. [15] analyzed the efficiency of styrene–ethylene–butadiene–styrene (SEBS) copolymer as an additive in asphalt mixtures used for cold patching purposes. Through the application of Brookfield viscosity and Marshall stability tests, the authors suggested final concentrations of 7.5% SEBS and 40% diesel oil by base asphalt weight, followed by an ascertained asphalt content of 4.6% against the weight of the mineral aggregate [16]. The SEBS-modified CAM reflected phenomenal improvements, as indicated by a 20.1% boost in Marshall residual stability and a 15.7% raise in the ratio of freeze–thaw splitting strength over the initial mixture; in addition, the improved mixture reflected a storability retention period of a minimum of two months [17].

Water-based epoxy emulsified asphalt mixtures (WEEAM) are the integration of water-based epoxy resin and emulsified asphalt with increased cohesion. Experimental tests based on Bi et al.'s research noted that WEEAM has better thermal stability: the dynamic stability improved by more than 98 times, and rutting depth reduced by over 11 times compared to the commonly used emulsified asphalt mixture [12]. WEEAM also had improved durability for freeze-thaw cycles and moisture; raveling-induced mass losses were lowered by over 66% compared to the emulsified mixture, and freeze-thaw split tests displayed remarkable moisture durability [12]. Nonetheless, the investigators noted the low temperature flexibility limitation compared to hot mix asphalt [13]. The findings highlight the future of polymer and epoxy modifiers in making sustainable advances in the development of cold mix solutions.

To highlight trends in performance, Figure 3 provides charts of Marshall stability and residual stability versus asphalt-to-geopolymer mass ratio, as reported by [20]. The results reveal the maximum stability occurred for a 4:3 asphalt-to-geopolymer ratio, then decreased with the geopolymer increase, while residual stability reduced with the increase of geopolymer dosage. These findings highlight the importance of the optimal dosage for providing a balance of durability and strength in geopolymer-modified cold mix asphalt (CMA).

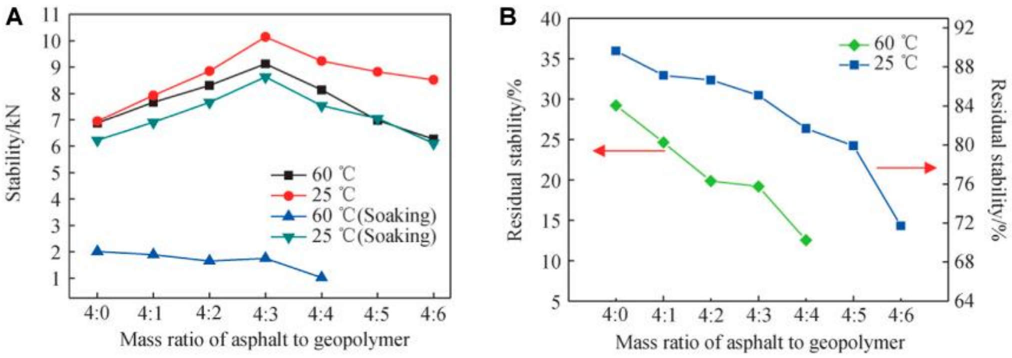

Figure 3. Marshall stability and residual stability of geopolymer-modified cold-mix asphalt at various asphalt–geopolymer mass ratios [20]

Table 2 summarizes the comparison of test types versus performance gain.

Table 2. test type vs performance gain

Test type (standard)	Performance gain vs control CMA	Mixture & dosage (representative)	Source
Resilient modulus / ITSM (EN 12697-26)	+≈43% at 2 days; reached HMA-level stiffness by ~7 days	CMA with 6% PSA + 2% CKD (PSA replaces LF; CKD 0–4% by agg. mass)	[2]
Wheel tracking rut depth @45°C, 10,000 cycles (EN 12697-22)	Reduced from 11.8 mm (LF) to 0.862 mm (6% PSA) and 0.497 mm (6% PSA + 4% CKD)	Same gradation; slab compaction	[2]
Fatigue (4-point bending, ε=150 με, 20°C)	~14× Nf (6% PSA) vs LF; ~16–21× with 6% PSA + 1–4% CKD; ≈2–3× HMA	Failure = 50% stiffness reduction	[2]
Resilient modulus / ITSM	≈13× higher than LF at 3 days; sustained stiffness advantage vs HMA/LF	Geopolymer CAEM (GGBFS + CCR) with waste $Ca(OH)_2$ solution	[6]
Moisture resistance (SMR / stiffness modulus ratio)	~40% higher than LF and >5% over HMA	Same mixture family as above (geopolymer CAEM)	[6]
Wheel tracking (permanent deformation)	≈5.5× shallower rut depth vs LF	Same mixture family as above (geopolymer CAEM)	[6]
Indirect Tensile Strength (ITS)	≈+20% vs control CMA	Emulsified cold mix + 2% cement + 1% FA + 1% GGBFS	[3]
Marshall stability	Increases to an optimum at 4:3 base asphalt:geopolymer; declines at higher additive contents	Cold-mix asphalt + geopolymer (optimum ratio 4:3)	[1]

Comparative analysis of previous studies

Table 3 summarises key parameters and findings from previous studies on CMA modification.

Table 3. Comparison of previous studies

Modification & mixture	Dosage or ratio	Observed effects	Source
Cold-mix asphalt + geopolymer	Asphalt : geopolymer ratio 4 : 3 optimum	↑ Marshall stability, rigid binder network, rapid early strength	[1]
CMA + paper-sludge ash (PSA) & cement-kiln dust (CKD)	0–6 % PSA; 0–4 % CKD	↑ stiffness & strength, ↓ curing time, internal bonding from PSA	[2]
Emulsified cold mix + cement/fly ash/GGBS	2 % cement, 1 % fly ash, 1 % GGBS	↑ indirect tensile strength (~20 %), ↑ early strength, dense matrix	[3]
Cold-mix asphalt + basalt fiber & cold-mix asphaltic liquid	Optimum asphalt–aggregate ratio; basalt fiber reinforcement	↑ initial strength (2.42 kN), ↑ molding strength (4.87 kN), ↑ immersion strength (6.79 kN), ↑ residual stability (92.8 %), ↑ freeze–thaw ratio (82.05 %), good storage stability	[4]
Polyurethane cold-recycled mixture	Glue to stone ratio 8–10 %; optimum 9 % binder; RAP 0–80 %	↑ adhesion to RAP, ↑ splitting strength at optimum binder ratio, ↓ high- & low-temperature stability with increasing RAP, ↑ freeze–thaw ratio when RAP < 40 %	[5]
Geopolymer cold asphalt emulsion mixture (GCAE)	GGBFS + CCR + waste $Ca(OH)_2$; 12.5 % bitumen emulsion	↑ ITSM (~13× reference after 3 days), ↓ rut depth (5.5× shallower), ↑ stiffness modulus ratio (~40 %), dense cementitious matrix	[6]
Cold-patching mixture + SEBS & diesel	7.5 % SEBS; 40 % diesel; asphalt content 4.6 %	↑ residual stability (20.1 %), ↑ freeze–thaw ratio (15.7 %), good storability	[8]
Waterborne epoxy–emulsified asphalt mixture (WEEAM)	WEEAM:mixture ratio 1:4; two-stage compaction	↑ dynamic stability (>98×), ↓ rut depth (>11×), ↑ moisture & freeze–thaw resistance, ↓ raveling loss (>66 %)	[9]

RESEARCH GAPS AND FUTURE DIRECTIONS

Despite the encouraging results, several shortcomings hold back the widespread application of adjusted CMA:

1) Early strength controlled by curing: the results indicate early-age gains as curing-sensitive. The recommendation is to test climate-relevant T/RH matrices and correlate moisture loss/emulsion break with ITSM/ITS/Marshall at 1, 3, 7, and 28 days.
2) CMA-specific nanoparticle evidence is sparse: Most nano studies are binder/HMA rather than mixture-level CMA. The recommendation is to run CMA mixed with nano materials with controlled emulsion type/charge and mixing sequence, and microstructure (SEM/FTIR).
3) Stiffness–fatigue balance must be optimised: Beyond the rough order of magnitude 4:3 stability optimum, higher additive levels tend to over-stiffen and pay fatigue penalties. The recommendation is to take balanced mix design (rutting/moisture vs fatigue) and optimise curing time as a design parameter.
4) Life-cycle assessment. Whereas certain modifiers offer functional benefits, e.g., photocatalysis, environmental implications and life-cycle costs must be assessed in order to justify their general use.
5) Other environmentally friendly modifiers, including waste-derived fillers and geopolymers, have shown promise, but more comparative studies are needed to determine the most sustainable and efficient additives under different conditions.

CONCLUSION

Cold mix asphalt (CMA) holds the potential for energy saving and emissions reductions but is still early performance is responsive to curing and mixture design. Optimal base-asphalt–geopolymer balance around 4:3 invariably optimizes stability, and PSA/CKD-based systems enhance stiffness, resilience against rutting, and moisture durability for practicable curing windows, but stiffening overly penalizes fatigue. The evidence base for nanoparticles at the mixture level for CMA remains limited compared with binder/HMA research, highlighting the necessity of CMA-adapted, dose–response research which holds emulsion chemistry conservative and confirms microstructure–property correspondences. Advanced microstructural techniques like scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), X-ray diffraction (XRD), and Fourier-transform infrared spectroscopy (FTIR) have confirmed that geopolymer reactions result in dense cementitious matrices and continuous binder networks in cold mix emulsions. Although modified CMA holds great potential for environmentally friendly pavement construction, future research should deal with optimizing additive contents, determining long-term durability and crack resistance, and conducting life cycle assessments to optimize its benefits in full.

AUTHOR CONTRIBUTIONS

Ammar Al-Attab Abdul Wahab: Data curation, Writing- Original draft preparation. **Khairil Azman Masri and Juhyuk Moon**: Conceptualization, Methodology.

FUNDING

The support provided by Universiti Malaysia Pahang Al-Sultan Abdullah in the form of a research grant vote number PGRS2303121 for this study is highly appreciated.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

ACKNOWLEDGEMENT

The authors would like to thank the Faculty of Civil Engineering Technology for providing the experimental facilities and to all technicians at Highway and Traffic Engineering Laboratory.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Fan, J.; Liang, H.; Sun, Z.; Chen, Z. Investigation on strength characteristics and mechanism of cold mix based on geopolymerization reaction. Frontiers in Built Environment 2023, 9, 1301126. https://doi.org/10.3389/fbuil.2023.1301126

[2] Dulai, A.; Sada, M.; et al. A sustainable cold-mix asphalt mixture comprising paper-sludge ash and cement-kiln dust. Sustainability 2022, 14, 10253. doi:10.3390/su141610253

[3] Lu, D.; Wang, Y.; Leng, Z.; Zhong, J. Influence of ternary blended cementitious fillers in a cold mix asphalt mixture. Journal of Cleaner Production 2021, 318, 128421. https://doi.org/10.1016/j.jclepro.2021.128421

[4] Sun, Z.; Li, Y.; Zhang, J.; He, S. Preparation and performance evaluation of cold mix asphalt mixture. Journal of Nanoscience and Nanotechnology 2020, 20, 4824–4831. doi:10.1166/jnn.2020.18498

[5] Li, Z.; Guo, T.; Chen, Y.; Zhang, T.; Tang, D.; Hao, M.; Zhao, X.; Liu, J. Study on road performance of polyurethane cold-recycled mixture. Polymers 2023, 15, 1958. doi:10.3390/polym15081958

[6] Dulaimi, A.; Al-Busaltan, S.; Mydin, M.; Lu, D.; Özkılıç, Y.; Jaya, R.; Ameen, A. Innovative geopolymer-based cold asphalt emulsion mixture as eco-friendly material. Scientific Reports 2023, 13, 17380. doi:10.1038/s41598-023-44630-5

[7] Huang, H.; Wang, Y.; Wu, X.; Zhang, J.; Huang, X. Nanomaterials for modified asphalt and their effects on viscosity characteristics: a comprehensive review. Nanomaterials 2024, 14, 1503. doi:10.3390/nano14181503

[8] Zhang, Y.; Chen, Z.; Zhang, X.; Zhang, Y.; Zhu, X.; Li, Q.; Liu, S. Investigation of the water damage resistance and storability of a SEBS-modified cold-patching asphalt mixture. Polymers 2022, 14, 5191. doi:10.3390/polym14235191

[9] Bi, Y.; Li, R.; Han, S.; Pei, J.; Zhang, J. Development and performance evaluation of cold-patching materials using waterborne epoxy-emulsified asphalt mixtures. Materials 2020, 13, 1224. doi:10.3390/ma13051224

[10] Abdul Hassan, N.; Hainin, M. R.; Hassan, S. A. Environmental and economic benefits of cold mix asphalt: A review. Journal of Cleaner Production 2022, 351, 131523. doi:10.1016/j.jclepro.2022.131523

[11] Al-Hdabi, A.; Al Nageim, H.; Ruddock, F.; Seton, L. New developments with cold asphalt concrete binder course mixtures containing binary blended cementitious filler (BBCF). Construction and Building Materials 2016, 134, 414-422. doi:10.1016/j.conbuildmat.2016.07.114

[12] Ghabchi, R.; Zaman, M.; Abbas, A. R. Laboratory evaluation of cold mix asphalt mixtures containing reclaimed asphalt pavement and polymer-modified emulsion. International Journal of Pavement Engineering 2019, 20 (6), 658-667. doi:10.1080/10298436.2017.1321415

[13] Khan, M. I.; Ali, N.; Abbas, N. Sustainable development of roads using cold mix asphalt: A review. Environmental Science and Pollution Research 2020, 27 (13), 15150-15160. doi:10.1007/s11356-020-08102-5

[14] Liu, J.; Zha, J.; Wu, S. Effect of additive on microstructure and mechanical properties of cold mix asphalt. Journal of Materials in Civil Engineering 2021, 33 (4), 04021015. doi:10.1061/(ASCE)MT.1943-5533.0003615

[15] Mashaan, N. S.; Ali, A. H.; Karim, M. R.; Abdelaziz, M. A review on using crumb rubber in reinforcement of asphalt pavement. The Scientific World Journal 2014, 2014, 214612. doi:10.1155/2014/214612

[16] Mohammadian, E.; Aghababaei, M.; Papagiannakis, A. T. Photocatalytic pavements: A review of nano-TiO_2 applications in asphalt technology. Journal of Cleaner Production 2020, 258, 120675. doi:10.1016/j.jclepro.2020.120675

[17] Yin, X.; Zhang, Z.; Zhou, X. Performance evaluation of cold mix asphalt using different asphalt binders. Construction and Building Materials 2021, 298, 123890. doi:10.1016/j.conbuildmat.2021.123890
513, 2019, doi: 10.1177/1754337119857434.

[18] H. Tan, L. Qin, Z. Jiang, Y. Wu, and B. Ran, "A hybrid deep learning based traffic flow prediction method and its understanding," *Transp. Res. Part C Emerg. Technol.*, vol. 90, no. January, pp. 166–180, 2018, doi: 10.1016/j.trc.2018.03.001.

[19] J. B. Caccese *et al.*, "Head and neck size and neck strength predict linear and rotational acceleration during purposeful soccer heading," *Sport. Biomech.*, vol. 17, no. 4, pp. 462–476, 2018, doi: 10.1080/14763141.2017.1360385.

[20] S. L. James *et al.*, "Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017," *Lancet*, vol. 392, no. 10159, pp. 1789–1858, 2018, doi: 10.1016/S0140-6736(18)32279-7.

[21] X. Huang, J. Sun, and J. Sun, "A car-following model considering asymmetric driving behavior based on long short-term memory neural networks," *Transp. Res. Part C Emerg. Technol.*, vol. 95, no. February, pp. 346–362, 2018, doi: 10.1016/j.trc.2018.07.022.