Proceedings of the 6th International Conference on Civil Engineering for Sustainable Development (ICCESD 2022), 10~12 February 2022, KUET, Khulna, Bangladesh (ISBN- 978-984-35-1972-6)

AN INSIGHT OF CHIP SEAL TECHNOLOGY FOR ROAD SURFACINGS

Mohammad Zakir Alam*[1]

[1]*Executive Engineer, RHD, Bangladesh, e-mail: mzab007@gmail.com*

***Corresponding Author**

ABSTRACT

Chip seal (CS) surfacing has been used since 1920 in road construction and practices. Primarily, road agencies were using CS for low volume road (LVR) construction. Gradually, this technology is widespread for high volume road (HVR) preservation in both high-income countries (HIC) and low-income countries (LIC) as a cost-effective surfacings technology. This study investigated the performance of CS technology as road surfacing materials through a systematic review (SR) approach to explore the longitudinal literature providing trials or databases. Following that, a multivariate linear regression (MLR) model is developed to show the relationship between CS pavement conditions with aggregate properties, road environment, climate parameters, and the like. Further analysis has been done for individual performance indicators, for example, Rutting and skid resistance to critically assess the serviceable life based on equivalent single axle load (ESAL) and year. The study identified that rutting and skid resistance loss are critical parameters limiting CS life. Thus, the review also estimates that CS life can be upto 6.5 years. One of the vital factors identified for premature CS failure is traffic loading. It was concluded that appropriate design, materials, CS types, sound construction, and maintenance would produce long-lasting CS roads. Briefly, cubical size crushed or natural aggregates (max. size 20mm in one layer) with high polished surface value (PSV) are found suitable. Besides, modified binders, for example, Polymer modified hot asphalt (PMHA), Polymer modified emulsion (PME), and Epoxy resin binder (ERB), showed better performance over conventional binders such as, penetration grade bitumen (PGB), cutback bitumen (CBB), and Tar. Especially, the Modified epoxy resin binder (MERB) gave a significant increase in mean stiffness and tensile strength compared to the control section, which was also found effective for skid resistance. This study addresses that HVR deteriorates earlier than LVR. More importantly, CS surfacings performed better on fair (F) to good (G) underlying surfaces. CS may be considered durable from engineering aspects. Notably, CS performance is positively correlated to atmospheric temperature, which may proves its climate resilience properties. The study concludes that allowable traffic volume on CS roads should be less than 1600 ESAL per day. The findings and MLR model developed in this review may add value to future research.

Keywords: *Chip seal; High volume road; Low volume road; Performance; Multivariate linear regression model*

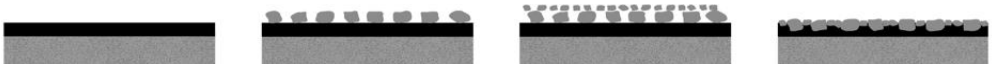
1.INTRODUCTION

Essentially, road plays a crucial role in economic and social growth since they ensure mobility, access to health, education, and jobs. Roads often deteriorate earlier than anticipated due to abrupt climatic changes such as high temperature, excessive rainfall, and rising sea levels. Along with that, insufficient resources also exacerbate road deterioration. Consequently, cost-effective and climate-resilient road surfacings were necessitated to face those challenges. CS technology was populated in this context due to its simple, rapid, cost-effective, and climate-resilient solutions to preserve the pavement layers and extend its life.

CS surfacings had been using since the 1920s. Primarily, it was used as a wearing course in constructing LVR. Gradually it has evolved into maintenance treatments that operated on both LVR and HVR over the last 75 years. The CS surfacings are being practised extensively in HIC examples for Australia, Canada, New Zealand, South Africa, the UK, and the USA (Gransberg & James, 2005). CS is also known as seal coats, bituminous surface treatment in Bangladesh, India; surface dressing in the UK; sprayed seal in Australia, chipseal or single-coat seal in New Zealand.

Chip seal comprises a thin layer of binder, sprayed onto the road surface, then covered with a layer of stone chippings (Figure 1). Generally, CS is constructed in single, double, or triple layers using natural/crushed stone or gravel or artificial aggregates with nominal sizes range 2-20mm. The aggregates protect the underlying layer from degradation and generate a macrotexture that supports vehicles with a skid-resistant surface. Tar, penetration grade bitumen (PGB) (70, 80/100), cutback, Polymer Modified Emulsion (PME), Epoxy resin binder (ERB), and the like are used as binders (RN39, 2016).

a) Single-Chip seal



b) Racked-in Chip seal

c) Double chip seal

Figure 1: Schematic representation of different types of CS surfacing (adopted from (RN39, 2016)

Unlike other surfacings, CS are firstly affected by ravelling, bleeding, or flushing and secondly by polishing and oxidation of binder. Raveling causes aggregate loss, polishing and flushing cause texture loss which diminishes skid resistance and makes our roads unsafe. Additionally, binders hardened with time, forming cracks on the surface, ingressing water, and weakening the base layer. Consequently, rutting, potholes and deformation occur on the chip seal surface. In this way, it shortens service life than design life which incurs increased Road agency cost (RAC), Vehicle operating cost (VOC), and Road user cost (RUC). The typical distress model of CS surfacing has shown in

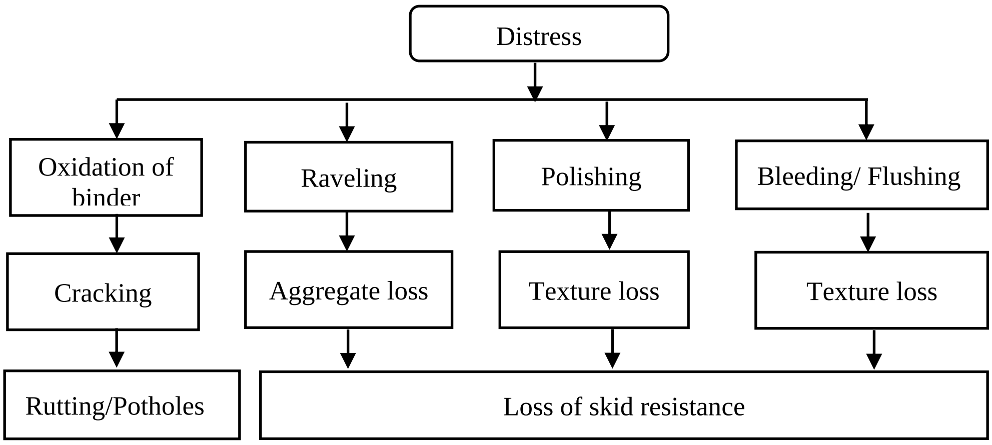


Figure 2: Chip seal distress model (adapted from (Gransberg & James, 2005)

Despite its cost-effectiveness, climate resilience properties, promising results against crack prevention, and improved riding quality, CS materials have not been utilized widely (CRISPS, 2021). As a result, an SR is conducted to identify the evidence and to investigate the durability of CS as road surfacing materials, comparing with other available practices, drawbacks of this technology, and develop an MLR model using MS excel. This paper summarizes the review findings and uses multivariate regression analysis to assess the performance of CS.

2.METHODOLOGY

This research was carried out following two methods.

2.1 Systematic Literature Review

A specialized application tool named EPPI Reviewer web (Beta) online software facilitates SR management. The SR is conducted following a review protocol which includes two stages.

i) Identifying and describing studies- includes exclusion criteria, search protocol, and screening studies

ii) Methods of synthesis- includes Weight of evidence (WOE), synthesis of evidence (Gough et al., 2017). More details have been discussed in section 3**.**

2.2 Multivariate Linear Regression (MLR) Analysis

After selecting relevant studies, the trial data is synthesized, analyzed, presented in equations, tables, charts, narrative methods and finally developed models (equations) for CS surfacings using MLR analysis with categorical data.

3.SYSTEMATIC LITERATURE REVIEW

A systematic literature review (SR) is defined as "a review of existing research using explicit accountable rigorous research method". SR is a secondary research based on primary research findings often used in practice and policy practice information (Gough et al., 2017). This review of CS for surfacings' will address the following question;

"What is the evidence of using chip seals on roads, and what evidence is there to assess the performance of chip seal technologies?”

The following section will provide definitions of key terms used in the review question.

3.1 Definitions

The SR followed a procedure based on the definitions below.

Table 1: Definitions

Terms	Definitions
Chip Seal	A chip seal (also known as a "seal coat") is a single coating of asphalt binder covered in embedded aggregate (one stone thick), with the primary goal of sealing fine fractures in the underlying pavement surface and preventing water infiltration into the base and subgrade (Gransberg & James, 2005).
Road	A path connecting two points is usually paved with asphalt or concrete for mobilizing motorized and non-motorized vehicles.
Technology	Resources (materials, equipment, capital) and management tools (e.g. economic appraisal, planning tools, computer tools), design, building, and maintenance procedures are all given as examples of technology.
Performance	Pavement performance refers to the level of service provided at any given time which is likely to be the cumulative effects of pavement distresses.

3.2 Exclusion criteria

The studies were screened and excluded as per the criteria shown below.

Table 2: Exclusion criteria

Criteria	Description
Language	are not written in English
Roads	do not investigate chip seal surfacing.
Technologies	not investigating methods, materials, equipment, and tools used in the appraisal, investment, design, construction, and maintenance of chip seal roads.
Study design and comparators	are not carried out pavement trials or database analysis with slice-in time investigations for at least 2 years from the implementation of the technology.
Outcomes	do not demonstrate that the technology is competent based on durability, surface condition, and efficiency.

3.3 The Search protocol

The search approach guided the review question based on three keywords: "Chip seal or Chipseal" AND "Road". The search engines used to find the relevant published papers were "Google.com" and "GoogleScholar". Again, the databases used are "ResearchGate", "SAGE Journal", "ScienceDirect(Elsevier)", "Scopus", "Web of Science", "trid.trb.org" and "Taylor & Francis online". Moreover, the published longitudinal studies from websites of World Bank (WB), Transport research laboratory (TRL), Overseas Economic Countries of Development (OECD) library, and the same also been taken into collection. Finally, the literature was imported to EPPI-Reviewer Web Beta online software using Perish 7, Mendeley and Endnote20 reference manager software in research information system (RIS) format to carry out the review process. In this systematic review, journals, articles, PhD/M.Sc thesis paper published reports and longitudinal studies relevant to CS surfacings used to analyze. Following that process, a total of 6709 documents were found to sort out. Then the above said software facilitated screening, coding, and storing the selected articles. The search process has shown in Figure 3.

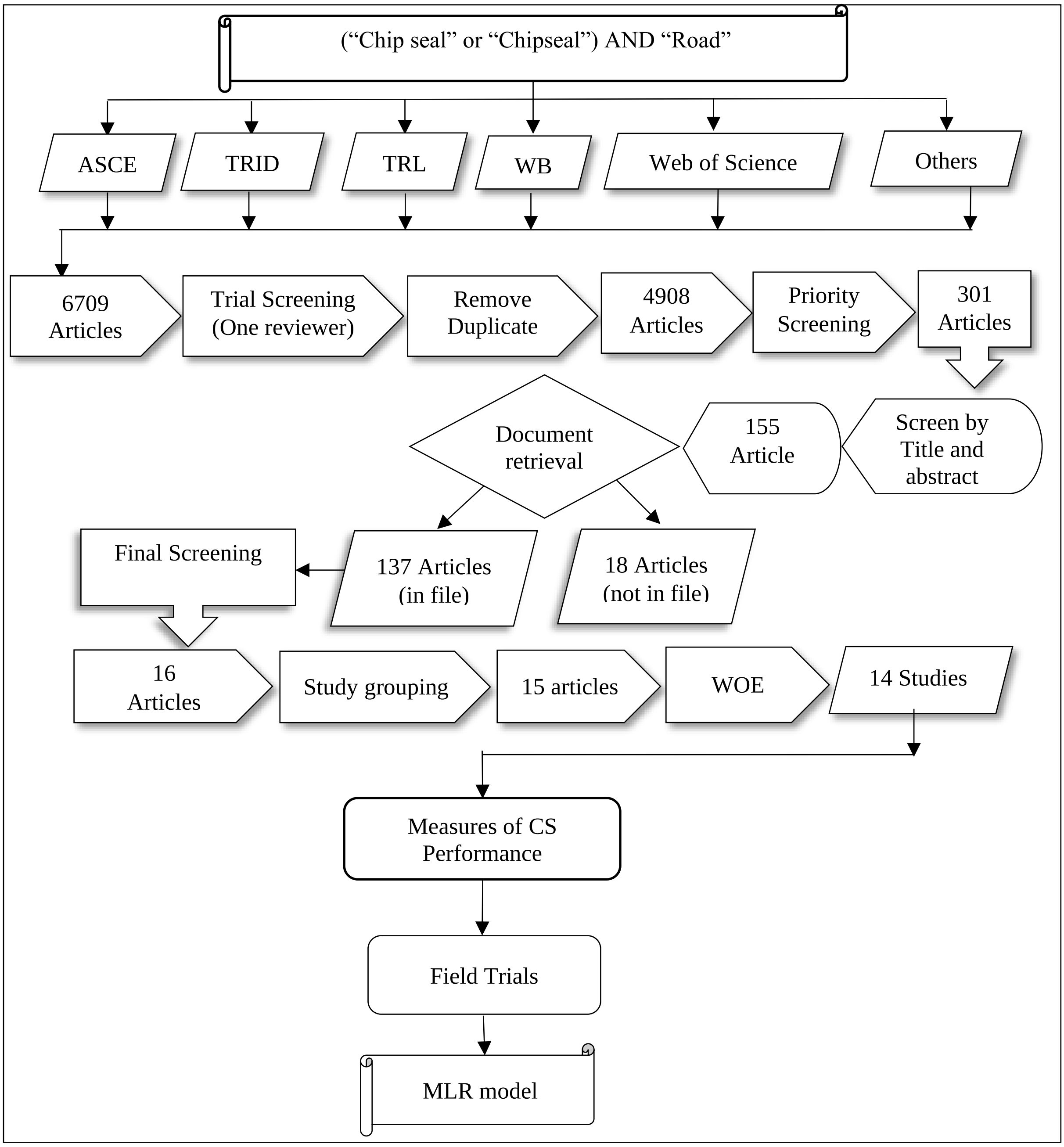


Figure 3: The search process

3.4 Weight of Evidence: evaluating the evidence quality

The quality and relevance of a study were assessed using a weight of evidence (WOE) framework. A framework used to judge studies as high, medium, or low quality has given in Table 3 below (Gough et al., 2017). For a study to receive an overall rating of high and therefore be used in the review stage, it needed to achieve at least two high and one medium rating in A, B and C categories.

Table 3: Weight of evidence

WOE	Tasks
A. Soundness of studies	***High:*** Methods and results for data collection and analysis are explicit and precise; sound interpretation based on findings; critical comparison with other work.

		Medium: Methods and results are satisfactory, and the findings somewhat support the interpretation. ***Low:*** Unsatisfactory methods and results sections; the findings do not warrant any interpretation of findings or interpretation.
B.	Appropriateness of study design for answering the review question	***High:*** At least two periodic repair cycles (about 6–12 years) are covered in road pavement trials or databases. Data on road conditions must be collected at least once a year and the frequency and type of maintenance performed—slice-in-time investigations of various in-service Chip seal roads with ages ranging from 6 to 12 years. ***Medium:*** Trials (or databases) that lasted one maintenance cycle (2–6 years). Throughout this time, data on road conditions were collected regularly. Slice-in-time studies will comprise a variety of in-service chip seal roads from 2 to 6 years. ***Low:*** Trials (or databases) with a duration of fewer than 2 years, or slice-in-time investigations of chip seal road with a period of fewer than 2 years.
C.	Relevance of the study focus to the review	***High:*** More than 3 sections of chip seal road with a length of at least 30 meters in any country. ***Medium:*** In any country, 1 to 3 sections of a chip seal road with a length of at least 30 meters. ***Low:*** A chip seal road section of at least 30 meters in length in any country.

3.5 Synthesis of evidence

The search was looking for several longitudinal studies that explained the use of technology throughout a CS roads life cycle (2–12 years) and demonstrated its long-term durability (or otherwise). As a result, data from the studies were synthesized using narrative methods and graphical presentation, showing the technologies durabilty as a function of the parameters that affect pavement conditions, for instance, Mean texture depth (MTD), roughness (IRI), rutting, skid resistance (Side friction co-efficient), and the like. A key objective was to develop a deterioration model based on those parameters to assess CS durability or performance.

3.6 Study Grouping

Fourteen high-quality studies were finally selected after WOE example for Brown (1986); Nicholls and Frankland (1997); Nicholls (1998); Wright (1976); Wang et al. (2020); Guirguis (2018); Denning (1978); Hitch (1981); Pittenger and Gransberg (2012); Shah et al. (2002); ITF (2017); Brown (1979); Henning (2008); and Woodbridge and Slater (1995). Those studies mainly presented trial/database results, which was synthesized to answering the review question. Further, the studies were divided into three groups. Firstly, grouped based on traffic levels example for LVR(ESAL≤50), MVR (51≤ESAL<125), and HVR(ESAL≥125). and then sub-grouped into CS types (e.g. single, double or triple) and binders.

4.RESULT AND DISCUSSION

4.1 MLR Model Using Categorical Data

MLR analysis is a technique for determining the degree of a linear relationship between multiple independent variables (x_1, $x_{2,\ldots\ldots}x_n$) with one dependent variable (y). This review was aimed to develop an MLR model to assess CS performance by synthesizing time-series data from ninety-two trial sections extracted from those studies.
Typically, an MLR model can be expressed as equation (1) shown below.

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + \ldots\ldots\ldots\ldots + b_nx_n \quad (1)$$

Here, x_1, $x_{2,\ldots\ldots\ldots}x_n$ are the independent variables and 'y' is the dependent variable.

4.1.1 Data input

In this analysis, pavement condition index (PCI) was considered the dependent variable(y). Other hands, traffic (ESAL), aggregate size (mm), treatment types (single/double/triple), binder types, temperature (°C), vehicle speed (kmph), underlying pavement conditions example for very good (VG)/ Good(G)/ Fair(F)/ Poor(P) were considered as independent variables (x_1, x_2, x_3.........x_n). The studies reported trial results in various indicators. Consequently, those data were combined into a single parameter (PCI) according to the condition rating (Table 4) and weightage factors (Table 5). The weightage factors were considered based on knowledge and evidence (RN39, 2016); (Morosuik et al., 2004); (Robinson et al., 1998). For instance, texture loss caused skid resistance loss (Gransberg & James, 2005). That is why it was given more weightage to skid resistance (SFC). Again, the roughness was given more weightage to rutting because it diminished riding quality and increased RUC (Wang & Gangaram, 2014) and the like.

Table 4: Chip seal pavements condition rating

Pav. Cond	CI	MTD	SFC50	SFC80	IRI (m/km)	Rut (mm)	PCI
VG	4	>1.10	≥0.60	0.35-0.45	0.0	0.0-3.0	3.5-4.0
G	3	0.91-1.1	0.51-0.59	0.46-0.50	0.0-3.0	3.1-6.0	3.0-3.5
F	2	0.51-0.9	0.36-0.50	0.51-0.59	3.1-6.0	6.1-12.0	2.75-3.0
P	1	0.0-0.5	≤0.35	≥0.60	>6.0	>12	<2.75

Table 5: Defects Weightage

Sl.	Combination	Weightage
1	MTD: SFC50: Rut	0.40:0.30:0.30 (+/-)
2	MTD: SFC50	0.60:0.40
3	MTD: SFC50: SFC80	0.40:0.30:0.30 (+/-)
4	Rut: IRI	0.20:0.80
5	MTD: SFC80	0.70:0.30 (+/-)
6	MTD: SFC50: Rut	0.60:0.20:0.20 (+/-)

4.1.2 Categorical data

Some data could not be quantified numerically, for example, traffic level, binders, and underlying surface conditions. That is why MLR analysis incorporated those categorical data as dummy variables using binary digits (1,0) (Table 6).

Table 6: Categorical data matrix (using dummy variables)

Traffic level (based on ESAL)			**Underlying pavement cond.**				**Binders**						
	LVR	HVR		VG	G	F		PGB	PME	ERB	CBB	PMHA	MERB
LVR	1	0	VG	1	0	0	PGB	1	0	0	0	0	0
HVR	0	1	G	0	1	0	PME	0	1	0	0	0	0
MVR	0	0	F	0	0	1	ERB	0	0	1	0	0	0
			P	0	0	0	CBB	0	0	0	1	0	0
							PMHA	0	0	0	0	1	0
							MERB	0	0	0	0	0	1
							Tar	0	0	0	0	0	0

Finally, PCI was set into Y-axis, and 16 predictor variables, including dummy variables, were placed on X-axis . Then MLR model was developed using excel,

The MLR model can be expressed in equation (2) as below.

$$\text{Pavement cond. PCI } (y) = 1.144+(0.106LVR-0.038HVR)+(0.468VG+0.397G+0.60F)+(-0.655PGB+0.099PME+0.873ERB-0.006CBB+1.192PMHA-0.324MERB)+0.034\text{Aggregate (mm)}+0.034\text{Temp}(°C)+0.013\text{Chip seal type}-0.0003\text{ Time}+0.002\text{Speed (kmph)} \quad (2)$$

The terminology of the model variables and the data input process has shown in Table 7 to understand the calculation.

Table 7: Terminology and data input process in MLR model

LVR	Low volume road (when LVR=1, HVR=0)
HVR	High volume road (when HVR=1, LVR=0)
VG	Very good underlying pavement (when VG=1, G/F=0)
G	Good (when G=1, VG/F=0)
F	Fair (when F=1, VG/G=0)
P	Poor (all VG/G/F/P=0)
PGB	Penetration grade bitumen (When PGB=1, other binders=0)
PME	Polymer modified emulsion (When PME=1, other binders=0)
ERB	Epoxy resin bitumen (When ERB=1, other binders=0)
CBB	Cut back bitumen (When CBB=1, other binders=0)
PMHA	Polymer modified hot asphalt (When PMHA=1, Other binders=0)
MERB	Modified epoxy resin binder (When MERB =1, Other binders=0)
Tar	For tar, all binders value=0
Chip seal type	Single=1, Double=2. Triple=3

4.1.3 Investigating critical parameters and serviceable life

The regression equations are developed to investigate critical parameters, and serviceable life. Here, 'y' denotes the dependent variables for example. Rut, SFC and 'x' denotes ESAL or year. The result found that CS pavement can fail due to rutting and SFC at ESAL 1600 per day. Thus identified rutting and skid resistance as the critical parameters. The maximum traffic volume that can be allowed must be less than 1600 ESAL per day over its life cycle (Table 8). Again, the study assessed its maximum life period could be upto 6.5 years.

Table 8: Comparison of CS performance based on ESAL

Indicator	Equations	Value (ESAL/Year)	Result (y)	Fail if	Remarks
Rut (mm) VS ESAL	$y = 3.0482x^{0.186}$	1600	12.02	>12	*Fail*
SFC VS ESAL	$y = 0.0045x^{0.7094}$	1600	0.81	≥0.60	*Fail*
SFC50 VS Year	$y = -0.0442x^2 + 0.3514x + 0.0096;$	7	0.32	<0.35	*Fail*

The MLR model is developed based on CS trial data of HIC (e.g. UK, USA, NZ, France) and Low and Middle Income Countries (LMIC) (e.g. Kenya). Thus, it may support CS activities in broad economic regions. Often, LIC and LMIC are suffered from fund scarcity, and decision making becomes critical in road investment. Optimizing a combination of aggregates, CS type, and binders may provide the expected output for a given road environment and period. After that, selection of the least-cost variety can be possible. Consequently, this model may support their small-scale CS road project appraisal. However, other factors such as design, materials, construction, and maintenance must be robust and appropriate for that particular site condition.

This model can suggest appropriate technology for CS surfaces in cold (<18˚C) and hot (≥18˚C) regions. For instance, it identified that rather than conventional binders (e.g. PGB, CBB, Tar), modified binders (e.g. PMHA, PME or ERB) could be suitable for both hot and cold regions. Again, PGB, Tar and CBB binders could be used for CS roads in hot areas with larger CS aggregates and layer specifications, which can be uneconomical. Regarding traffic level, this model also identified that HVR roads require higher material specifications than LVR roads for the same expected life and pavement conditions. Thus, this model may support cost-effective construction and maintenance planning for CS road works in hot and cold regions. Other hand, this model can be able to assess CS pavement conditions based on given time and other known independent variables. Thus, it can be possible to determine maintenance needs of CS surfacing.

Unlike other deterioration models, the MLR model provides a unique opportunity to assess overall CS pavement performance based on mentioned independent variables. The review showed that the same approach could also be used to develop equations for individual indicators. However, some complex issues identified have been discussed below;

The MLR model can predict how expected changes in the temperature under extreme climate conditions would affect CS strategy and design. The model considered average air temperature. It found that PCI increases with temperature and vice versa. The context is more complex for freezing temperatures, and multiple freeze-thaw cycles may lead to premature CS surface failure. The model shows that high materials specifications may give a better result. Again, the CS laying should be restricted in freezing climates. Further investigation is required in that case.

The MLR model showed that the underlying surface coefficient for F(0.60) has a higher value than VG (0.468) and G(0.397), which may seem unlikely. But the data analysis showed that most 'F' condition roads were LVR, and most 'G' and 'VG' condition roads were HVR class. As a result, MVR and HVR roads deteriorated faster than LVR due to traffic volume, proving the significant CS deterioration factor. Again, looking at the binders co-efficient, modified binders showed more effectiveness than conventional binders. The model indicates that PMHA binder will be more effective in HVR roads of both cold and hot regions than others. However, few studies suggested that ERB would be effective for difficult sites, for instance, bends or curves. In such a particular case, alternatively, it can carefully select the appropriate binder first and then optimize the aggregate sizes and layer types to get the desired output.

Again, this model illustrates that PCI improves with aggregate sizes. Oppositely skid resistance decreases with chip size, which is a complex situation that needs to be optimized. Roberts and Moffatt (1999) illustrated that skid resistance could be a dominant factor at low speed, but MTD will be the dominant factor to consider at high speed. So, this review suggests that aggregate size is to be selected based on the average SFC50 value (say, 0.5). For this SFC value, the corresponding aggregate size is 20mm. Notably, this chip size also satisfies the required MTD.

Mentioning that though regression analysis is a powerful tool, it is more reliable when dealing with larger datasets. Secondly, various standard test methods were used for trial investigations in the selected studies; for example, Road note 39 was used for Kenya, DMRB was used for UK trials, ASTM448, AASHTO 1993 were followed in USA trials. That is why it would require more extensive and consistent datasets to validate the model. However, this MLR approach may guide in developing the CS performance model for any interested group.

This study identified that rutting and skid resistance was the critical parameters (Table 8). It is to mention that rutting increased with ESAL and temperature. The study argues that CS might not be feasible if the underlying pavements state was poor in a rutting context. Also, it was found that skid resistance decreased with the increase of ESAL. In this regard, appropriate binders (e.g. MERB) along with hard aggregates (high PSV) might improve skid resistance. Although the initial results of MERB were satisfactory, it was hard to conclude based on 3-years trial data (ITF, 2017). So, further trial data of at least two periodic cycles are required. Again, the effect of MERB on other indicators, for example, MTD, rut, and the like, also need to be investigated.

5. CONCLUSION

Chip seal technologies may be considered viable based on engineering point of view if their design, construction, and maintenance are robust. The review critically analyzed and estimated CS life that may be upto 6.5 years. Based solely on these facts, it would not be feasible to conclude that CS technologies are sustainable as a whole. Despite all, there is sufficient evidence to improving the CS surfacings performance and life span as well. Appropriate design, materials selection, quality control, and maintenance will produce a durable CS road. However, some vital issues, traffic loading (≥1600 ESAL per day), binder hardening, and underlying pavement conditions that can result in CS roads premature failure, should be given attention. The findings and MLR model developed in this review may add value to future CS research.

ACKNOWLEDGEMENTS

I would like to greatly thanked for their contributions to the study **Dr Michael Burrow**, Senior lecturer, School of Civil Engineering**,** The University of Birmingham. Also the I would like to thank for Funding for EPPI review (web) software purchasing, Climate-resilient sustainable road pavement surfacing (**CRISPS**) project Led by University of Birmingham, School of Civil Engineering**.**

REFERENCES

Brown, J. R. (1979). Interim report on the performance of surfacings for maintaining bituminous roads:A1 Buckden (1975-1977). *TRL*. https://trl.co.uk/uploads/trl/documents/SR476.pdf

Brown, J. R. (1986). The performance of surfacings for maintaining bituminous roads: A1 Buckden (1975-1982). *TRRL*. https://trl.co.uk/uploads/trl/documents/RR070.pdf

CRISPS. (2021). *HVT-CRISPS: Climate resilient sustainable road pavement surfacings*. University of Birmingham. Retrieved 2/7/ from https://more.bham.ac.uk/hvt-crisps/about-the-project/

Denning, J. H. (1978). High-performance surface dressing: 2. Road experiments with new thermosetting binders. *TRL*. https://trl.co.uk/uploads/trl/documents/SR416.pdf/

Gough, D., Oliver, S., & Thomas, J. (2017). *An introduction to systematic reviews*. SAGE.

Gransberg, D. D., & James, D. M. B. (2005). *Chip Seal Best Practices: A Synthesis of Highway Practice*.

Guirguis, M. (2018). *Design and performance assessment of chip seal applications* Lowa State University]. https://lib.dr.iastate.edu/etd/16770

Henning, T. F. P. (2008). *The development of pavement deterioration models on the state highway network of New Zealand* The University of Auckland]. https://researchspace.auckland.ac.nz/handle/2292/4236

Hitch, L. S. (1981). *Surface Dressing in Developing Countries: Research in Kenya* (TRRL LABORATORY REPORT 1019, Issue. https://trl.co.uk/uploads/trl/documents/LR1019.pdf

ITF. (2017). Long-life Surfacings for Roads: Field Test Results, ITF Research Reports. *OECD Publishing, Paris*. http://dx.doi.org/10.1787/9789282108116-en

Morosuik, G., Riley, M. J., & Odoki, J. B. (2004). Modelling road deterioration and works effect. In (2nd ed., Vol. 6). Edgbaston, Birmingham, B15 2TT, United Kingdom: ISOHDM Technical Secretariat, School of Civil Engineering, University of Birmingham.

Nicholls, J. C. (1998). *Road trials of Stone Mastic Asphalt and other thin surfacings* (ISSN 0968-4107). (TRL REPORT 314, Issue. T. R. Laboratory. https://trl.co.uk/uploads/trl/documents/TRL314.pdf

Nicholls, J. C., & Frankland, D. P. (1997). *The long-term performance of a surface dressing trial on A413 , Amersham Prepared for Quality Services , Highways Agency* (ISSN 0968-4107). (TRL REPORT 261, Issue. https://trl.co.uk/uploads/trl/documents/TRL261.pdf

Pittenger, D. M., & Gransberg, D. D. (2012). Performance-Based Life Cycle Cost Analysis: A Chip Seal Field Test Case Study. Proceedings, 7th International Conference Maintenance and Rehabilitation of Pavements and Technological Control,, Auckland, New Zealand.

RN39. (2016). Design guide for road surface dressing. In D. Bateman (Ed.), (7th ed., pp. 1-71).

Roberts, J., & Moffatt, M. (1999). *HDM-4 Model Testing for Selected Australian Conditions : Road Deterioration Models for Chip-Sealed Granular Pavements-CALIBRATION STUDY(HDM-4 Beta Version 3.0), Contract Report RC* (N.BS. 9813). A. T. Research.

Robinson, R., Danielson, U., & Snaith, M. (1998). *Road maintenance management: concepts and systems*. PALGRAVE.

Shah, W. T. S., Paul, H., & Abadie, C. (2002). Performance of Louisiana's Chip Seal and Microsurfacing Program, 2002. *Transportation Research Record 1795*, *Paper No. 02-4075*, 3-16. https://journals.sagepub.com/doi/10.3141/1795-01

Wang, H., Al-Saadi, I., Lu, P., & Jasim, A. (2020). Quantifying greenhouse gas emission of asphalt pavement preservation at construction and use stages using life-cycle assessment. *International Journal of Sustainable Transportation, 14*(1), 25-34. https://doi.org/10.1080/15568318.2018.1519086

Wang, H., & Gangaram, R. (2014). *Life Cycle Assessment of Asphalt Pavement Maintenance (No. CAIT-UTC-013)* CAIT-UTC-013). C. f. A. I. Transportation & T. S. U. o. N. J. Rutgers. https://rosap.ntl.bts.gov/view/dot/28057

Woodbridge, M. E., & Slater, C. W. N. (1995). *Development of a reduced specification for surfacing aggregate on low traffic roads in Botswana*. https://trl.co.uk/uploads/trl/documents/PR115.pdf

Wright, N. (1976). *Surface dressing on concrete roads*. TRRL. https://trl.co.uk/uploads/trl/documents/LR736.pdf