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Modification of Hot Mix Asphalt and its Resistance to Pavement Distresses: A Scientific Metric Analysis and Bibliometrics Review

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Abstract

Hot Mix Asphalt (HMA) technologies have undergone significant advancements in pavement engineering, with modern modifications enhancing its rheological properties and increasing resistance to cracking, rutting, and moisture damage. These improvements have contributed to extending pavement lifespan and reducing maintenance costs, making HMA a more sustainable choice for infrastructure. Polymer-modified and rubberized asphalt mixtures have demonstrated superior performance compared to conventional asphalt, offering enhanced durability under heavy traffic loads and harsh environmental conditions. Additionally, the use of recycled materials, such as rubber from discarded tires, improves durability while reducing environmental impact. These technologies are widely applied in infrastructure projects, including highways, bridges, tunnels, industrial areas, and airport aprons, leading to improved overall performance and lower maintenance costs. This study will analyze research trends on the effects of modified asphalt mixtures on pavement performance using the Dimensions database and VOS Viewer software. Furthermore, the study will identify key contributing countries and institutions, as well as examine research collaboration networks among scholars, aiming to provide insights that support the development and enhancement of modified asphalt mixtures for superior performance and greater sustainability.

Keywords: Pavement distresses, Modified asphalt mixtures, Hot mix asphalt, Polymer modification, Bibliometric analysis.

1- Introduction

As the number of heavy cars and traffic increases, asphalt failures are becoming more prevalent. Asphalt pavement breaks easily at low temperatures, although deformation and rutting occur as the ambient temperature rises[1]. Modifying bitumen characteristics extends pavement life and improves quality, leading to lower repair and maintenance costs. Modifiers have been utilized in recent decades to improve the adherence and characteristics of traditional pure bitumen and asphalts, resulting in longer-lasting pavements[2]. The modification of Hot Mix Asphalt (HMA) is crucial for enhancing the durability and performance of pavement structures, particularly in addressing various pavement distresses that compromise their longevity. By incorporating various modifiers, such as polymers and additives, researchers aim to significantly improve the mechanical properties of HMA, thus mitigating issues such as cracking, rutting, and moisture damage. This review will explore the recent advancements in HMA modifications and their effectiveness in overcoming these prevalent pavement distresses. The focus will be on various modification techniques, including polymer modification, rubber additives, and the incorporation of recycled materials. Additionally, the review will assess the performance of these modified HMA in mitigating issues such as rutting, cracking, and moisture susceptibility. This assessment will provide valuable insights into the effectiveness of various additives and modifications employed in the design of hot mix asphalt HMA, thereby contributing to the development of more durable pavement solutions [3]. Recent advancements in asphalt technology have led to innovative modification techniques that significantly improve the material's resistance to common distresses such as cracking, rutting, and moisture damage. These modifications not only enhance the durability of HMA but also extend its lifespan, making it a more sustainable choice for infrastructure development. As the demand for high-performance pavements increases, understanding these innovative techniques becomes crucial for engineers and researchers alike. This review explores the various modifications applied to HMA to enhance its efficiency and robustness against prevalent pavement failures [4]. Scientists and engineers are always seeking to enhance the features of asphalt mixes, such as their stability and longevity, by putting new additives into the bitumen or the asphalt mixture [5-7]. Moisture damage is a common cause of pavement failure worldwide, which can be seen as an economic strain. Moisture damage may cost millions of dollars to maintain and repair damaged pavements[8-10]. Polymer-based pavement offers improved resilience to rutting and thermal cracking, as well as decreased susceptibility to fatigue failure due to temperature and stripping. Polymer-modified binders have several enhanced features, including a greater softening point, elastic recovery, cohesive strength, ductility, and viscosity[11].

Although numerous studies on asphalt mixture modification exist, bibliometric analysis has not been sufficiently addressed to identify the major research trends in this field. This study fills this gap by using data analysis tools such as VOS viewer and Dimensions to map global research in this field, contributing to new insight into the scientific trends in asphalt mixture modification.

2. Background and Significance

HMA is a critical material used in pavement construction. It is known for its versatility and durability, yet it faces various distresses over its lifespan that can affect its performance. Understanding the factors that contribute to the degradation of HMA is essential for enhancing its performance and longevity. Understanding these distresses is crucial for developing effective modification strategies as they directly impact the performance and longevity of HMA pavements. Additionally, this section will highlight various modification techniques that have been implemented in recent studies to enhance resistance against these distresses. These techniques range from the incorporation of polymer modifiers to the utilization of recycled materials, each technique aimed at improving the mechanical properties and durability of HMA. Moreover, the significance of these modifications lies not only in enhancing performance but also in promoting sustainable practices within pavement engineering [12]. Understanding HMA modifications is crucial for enhancing pavement durability and performance. By exploring various additives, such as polymers and rubber, researchers can develop solutions that improve resistance to environmental stresses while maintaining structural integrity over time. Incorporating advanced modifiers into HMA formulations significantly enhances resistance to common distresses like cracking, rutting, and fatigue. This not only extends roadway lifespan but also reduces maintenance costs and improves user safety [13].

This study aims to explore the limitations of current research on modified asphalt mixtures, recent developments, and emerging research trends using informatics mapping and bibliometric analysis. Although a quantitative review approach is adopted, these analytical tools cannot eliminate all biases and limitations present in traditional studies. This review is one of the first studies to apply bibliometric analysis on a large scale within the limits of available data, enabling it to categorize the latest innovations in the characterization of modified asphalt mixtures with greater accuracy and clarity.

3. Characteristics of HMA

HMA is a mixture primarily composed of graded mineral aggregates, asphalt binders, and additives that make it workable for traffic at high temperatures. HMA has been extensively used for roadway construction. It has a variety of properties oriented for use, such as flexibility in different variations of distress, oxidation for life, durability for all traffic and climate conditions to resist rutting, fatigue cracking, etc., and to withstand both slow, time-based, and fast thermal fatigue. Thus, to utilize HMA for whatever type of application, say speedy construction or properties required by the end-user - low noise and ride comfort are rapidly becoming important - the interplay of all HMA components' properties listed earlier must be not only freely accessible to and understandable by any HMA plant operators with a supervisor on site but also effectively applied in mix design [14].

Oxidation resistance is influenced by asphalt penetration grade and viscosity values. Paving or blowing penetration grade asphalt results in thick films, longer durability journeys, and rapid HMA hardening. The higher the HMA viscosity concerning the solar collector unit, the longer the life of the pavement in service because chips do not carry as long. Hardened asphalt, due to its high viscosity, has a remarkable set of characteristics and performs daily more effectively as a medium and long asphalt-graded pavement to ensure long life. Generally, constant use of lower-viscosity asphalt pavements usually experiences more rapid distress. Ensuring compatibility between aggregates and asphalt by performing mix design determines the longevity of hot mix applications at lower and upper levels. Perhaps, to a lesser extent, this proof describes another highway waterproofing asphalt pavement service life system [15].

3.1. Composition and Properties

HMA is broadly composed of aggregates, two grades of asphalt binder (one as a filler), and optional additives to improve its performance. The HMA consists of natural or crushed aggregates and recovered or virgin asphalt binder that is heated to high temperatures to be mixed by spreading onto the road base and compacted. The aggregate, which dominates the pavement mix, has to withstand the loads to be supported and the environmental conditions it faces. This new mixture has to maintain a scaled-up aggregate skeleton, which facilitates the load transfer from the pavement surface to the road base, and adequate densities of HMA to resist moisture damage. The asphalt binder, which acts as both a "glue" and a "lubricant", has to fill the voids within the aggregate matrix and support the mix structure, thereby enhancing stiffness. However, if the HMA surface is heated, the asphalt binder becomes weak and fluid, applying less shear.

When the road surface temperature drops, the viscosity increases to preserve the aggregate distribution. Finally, new mixtures should be designed such that under fatigue and thermal stresses, the binder and/or aggregate material does not undergo a significant separation or deform excessively [16].

As soon as it is placed and then long after, it is important to predict the performance of a particular mix. The most important HMA properties that are typically evaluated are the complex modulus, phase angle, permanent deformation parameter, toughness, which is the energy absorbed by the specimen, and the intermediate strength of the HMA mix. Other properties include but are not solely constrained to flow time, the density of vibrated compaction, cohesive strength, and isolation of the aggregate particles from one another when one or more specimens are laid on top of each other and compacted. Collectively, they indicate additional performance characteristics, such as the viscosity of the binder, whose resistance to flow will help indicate the performance [17].

4. Common Pavement Distresses

The heavy traffic load may cause pavement distress that significantly influences pavement performance. According to characteristics and penetration depths, pavement distress can be collectively classified into several categories. Some types of distress are predominantly longitudinal cracks along the wheel path, for example, eleven percent, and major and non-decreasing longitudinal ruts. These types of distresses are called 1st distresses. Besides, there are two categories of distress, e.g., two percent minor transverse cracks and minor non-decreasing transverse ruts, classified as secondary distress. Distress is defined as any surface degradation or type of deformation that affects either the physical appearance or the ability of the structure to function as intended, and such interference reduces the predicted service life. A majority of the studies indicate that various deficiencies affecting bituminous pavement are cracks and rutting, which show the predominant distress of the pavement [18]. It is also mentioned that almost 70% of the world's hard surface roadways are composed of hot-mix asphalt. Due to the enhancement and evolution that occurred over the last 20-30 years in the field of hot-mix asphalt, researchers are foreseeing new constituent mixtures, namely, warm mix asphalt. Over a period of time, asphalt-based pavement will definitely show some signs of distress, such as cracking and rutting or severe damage due to wear and tear near the surface of the road. It is generally recognized that environmental conditions, traffic loads, and various chemical factors can lead to the failure of hot-mix asphalt and can cause distress to occur. Modifying hot-mix asphalt to address distress will minimize the cost of repairing roads and improve road safety by increasing the lifespan of paved roads. This encompasses the safety factor and poor maintenance expenses to proper hot-mix asphalt compared to regular available hot-mix asphalt constituents [12].

5. Factors Influencing HMA Resistance

HMA pavement offers a high level of performance and comfort when traveling. However, the presence of various distresses can affect the sustainability of the pavement. The performance and durability of HMA are also subjects of discussion. Different studies have been devoted to looking into parameters that could influence the existence of HMA pavements. Studies have shown that various factors could influence the resistance of HMA to different kinds of distress. These factors include environmental conditions and terrain, material properties, asphalt binder characteristics, such as grade and properties, selection of aggregates and mineral fillers with good compatibility and durability, traffic load and frequency, and type of vehicles. By understanding and considering these parameters, engineers can design and build a pavement that will have the necessary resistance [19-23].

Many investigators have provided a wealth of information on the mechanism of HMA in materials research and how HMA quality relates to three other factors: design, production, and service. Some have studied the interaction between these designs, materials, production, and service factors and interpreted the results with the help of concepts from the scientific field. Good materials in the HMA production process must include a high degree of chemical and mechanical properties of the HMA as well as resistance to the most common types of distress in HMA compounds. For the lifespan of the HMA pavement to be long, HMA must develop distresses according to design. Hence, HMA pavement must have the necessary mechanical properties (resistance) to loads. Without maintenance, the service life of an HMA lane is not the same as the design. Pavement wear is the result of the interaction between pavement and the atmosphere, traffic, and administration. Interactions are complex and can be influenced by many factors. Research must involve direct experimentation, including field studies, to fully understand the pavement wear process. All types of distress on the pavement are the result of interactions between the effects exerted by the material, type of load, and environmental effects [24-26].

5.1 Material Properties

The HMA performance and its resistance to possible pavement distress are in direct relationship with the mechanical performance and the properties of the HMA materials at various pavement temperatures and loading conditions. The "mechanical response" of any material under load is influenced by its constitutive relationship and varies in direct correlation with its "stiffness" (more consistent with solid behavior) and "viscosity" (more consistent with liquid behavior). The "stiffness" describes the ability of the material to resist deformation under load at low strain levels, particularly the high-temperature performances and related "rutting" distresses. The "viscosity" also has an important impact on low-temperature performances and related "cracking" distresses. As a consequence, the "stiffness" (indicated by the modulus value), together with the "viscosity" and the "extensibility", are the three major parameters that characterize the "binder quality" and the ability of a bituminous material to resist distress. The mechanical response of the whole asphalt concrete is significantly affected by the shape and grading of the aggregates[27, 28].

A better understanding and comprehensive modelling of the concrete properties represent an extremely useful tool for designing the mix to be used in a specific pavement. For some projects, the contribution of material science, which is constantly working to develop new technologies regarding bitumen-based materials, is of great importance. Regarding the main materials of this state-of-the-art argument, various general aspects of the constitutive relationships are updated with specific attention from mix designers towards the possibilities offered by modifications in the rheological properties, generally made by the addition of polymers in specific bitumen/binder materials [29, 30].

The economic and environmental benefits should be evaluated for the possible proactive effects on the durability of asphalt-wearing course pavements. Some of the recent ongoing effects devoted to the research of high-resistance pavement are also described hereinafter. The main interest is given to the latest and most significant international developments within the materials field, as they are particularly related to European specifications and possible advances already incorporated in the most recent standards. The description of the viscoelastic and viscoelastic-plastic constitutive approaches in the real-life problem of traffic environments is also briefly outlined. This section reports the development of high stiffness and stiffness-extended polymer-modified materials from base bitumen's of different sources using the addition of block copolymers [31, 32].

6. Methods of HMA Modification

Numerous methods have been incorporated to modify HMA in order to enhance the responses and performance of HMA against different pavement distresses. Polymers, mostly SBS and elastomer, can be used to modify the properties of conventional binders during their manufacturing process. One mechanism of polymer modification is adsorptive, which supports the enhancement of PMB to resist the oxidative hardening of conventional binders and improve the performance of mixtures against rutting. Besides improving the fatigue resistance of mixtures, other purposes of PMB layer inclusions are to improve binder drainage and reduce concrete pavement cracking. Moreover, the composition of MAC-10Ps has also shown high results of permanent deformation resistance. A reduction in both permanent and transient deformation of HMA is attained after using PMB along with aggregates of smaller size and the addition of stabilizer, wet process crumb rubber modification [33-35].

The calibration, HAM, and MAC-10 mixture obtained using a combination of 12% rubber with 0.6% blend of stabilizing oil content are capable of preventing raveling and resisting permanent deformation even at a high concentration of 2.4% of larger-size 4.75 mm crumb rubber particles. The public expectation is that heated tire scrap and crumb rubber have the potential benefits and ability to enhance durability, flexibility, and pavement rut resistance apart from reducing cracking formation in the HMA mixture. The most important effect of the use of crumb rubber modifier in the HMA mix design is the increase of the drain down-resistance factor from 134% to 285%, a reduction of PSV drain down from 8.6% to only 3.0%, and an increase in the rut-resistance factor from 0.83 to more than 1.0. The results demonstrated that trackless behaviour in an HVS for more than 5 million ESALs could be achieved when the asphalt binder is modified. This modification creates a beneficial interface between the asphalt and the stone. The 'stone on stone' friction is reduced, providing major resistance to horizontal creep or rutting. Additionally, aggregate particles have increased stability and reduced permeability [36, 37].

6.1 Additives

Asphalt modifications involve the incorporation of various additives to enhance the performance and durability of asphalt mixtures. These materials help reduce the exploitation of natural resources and help enhance the performance of asphalt pavements. These additives have been proven to significantly improve the fatigue life and bonding properties of asphalt mixtures. In addition, modified bitumen mixtures exhibit stability, density, and water resistance, making them suitable for highway construction [38-40].

HMAs can be modified in various ways to improve their performance and minimize the negative impacts of various distresses. The most commonly used method involves the use of additives, which can change the properties of HMAs significantly, enhancing their resistance to distress. Commonly used additives include polymers, crumb rubber, anti-stripping agents, and fibers. The choice of a particular additive is very important; it cannot overshadow the possible distress and the target performance. There have been many studies on the application of additives, in particular polymers; such studies often report very good performance. The main problem with additives is the cost, but some studies have proven that the use of additives might lead to savings on the maintenance of the pavement [41].

When changing the mix design in Recycled Asphalt Pavements mixtures, it is important to make the HMA resistant to age hardening. Using lime to stiffen the asphalt leads to very good results; such mixtures have better resistance to permanent deformations, which makes it possible to think about a thinner structural layer. Incorporating additives in HMAs is a promising alternative to improve their performance and reduce the negative impacts of distress, particularly cracking. However, it is imperative to understand the interaction among additives, HMAs, and different pavement distresses in order to facilitate the prediction of pavement performance and opt for the best additive application mix design to assist in resolving this issue. Additives are employed to alter the properties of HMA, leading to an improvement in its resistance to pavement distress. In particular, these additives enhance the performance of the base HMA in terms of their resistance to fatigue cracking and moisture-induced damage [42].

Among the different additives, the use of polymers in different forms aims to improve the base HMA's resistance against low temperatures, while fibers and rubber aim at reducing the tensile strain capacity of the base HMA, rendering it very good resistance to weathering distress. However, such targeted use leads to concerns regarding the high-energy distress performance of modified HMA. Although various studies involving the incorporation of particular types of polymer additives have been reported, attempts to study and understand the usage of different polymer additives to alter the mechanical and distress performances of HMA are limited [12].

6.1.1. Styrene-butadiene-styrene(SBS)

SBS has been widely used to modify the properties of asphalt at elevated temperatures. SBS is a typical two-phase thermoplastic polymer in which solid polystyrene blocks are bonded to rubbery polybutadiene blocks[43, 44]. When SBS polymer is used in roads, it reduces fatigue cracks and also mitigates the damage caused by the sun's rays in the summer, which leads to improved performance in hot regions, making roads longer-lasting, more comfortable to drive, and requiring less maintenance[44].

6.1.2. Novolac

Novolac resins enhance the impact strength of asphalt mixtures, improving their ability to withstand fracture under pressure. It also improves the flexural strength of asphalt to maintain structural integrity under pressure[45]. The use of novolac resins may alter the kinetics of asphalt curing, which could improve its thermal stability and performance at higher temperatures. Improved flame retardancy is a feature of Novolac-modified asphalt that improves road safety[46].

6.1.3. Crumb rubber (CR)

Crumb rubber (CR), which is formed from used tires, has been widely used as a modifier for asphalt binders due to the constantly growing volume of discarded tires. It is acknowledged as an eco-friendly technology[47, 48]. Furthermore, surface treatment helps to increase the compatibility of CR particles with matrix asphalt for increased stability during storage[49, 50].

6.1.4. Polyethylene(PE)

By using PE in asphalt, less virgin bitumen is required, which supports a circular economy and lowers carbon emissions related to asphalt manufacturing. Utilizing waste PE prolongs the life of road networks and aids in recycling initiatives, tackling the worldwide plastic waste challenge[51, 52]. PE is a compaction additive that improves asphalt mixture compaction and decreases rut depth. Aggregate thermoplastic PE coatings increase moisture resistance, reducing peeling and enhancing durability in general[52, 53].

6.1.5. Ethylene vinyl acetate(EVA)

EVA makes asphalt binders more rigid, raising their softening points and lowering their penetration values. This improves their ability to withstand rutting and deformation in hot weather. It has been demonstrated that adding EVA to asphalt mixtures increases their resistance to rutting and permanent deformation under high traffic loads[54, 55]. EVA modification increases the adhesion of asphalt to aggregate, which is essential for extending the life of pavement surfaces. In addition, EVA reduces the likelihood of cracking at low temperatures, resulting in increased overall durability of the asphalt mixture[56, 57].

6.1.6. Styrene-butadiene-rubber(SBR)

SBR improves elongation at break and low-temperature relaxing capabilities, which are essential for avoiding cracking in cold environments. SBR is added to asphalt to assist in preventing thermal breakdown during preparation, maintaining the asphalt's low-temperature performance. Better ageing resistance is exhibited by SBR-modified asphalt, which is crucial for sustaining performance over time[58, 59]. Tests have shown that adding more SBR to asphalt mixes results in greater softening points and less penetration, which enhances the mixtures' resistance to rutting. For asphalt pavements to last a long time, SBR improves the interfacial bonding strength by increasing the adherence between asphalt and aggregates[60, 61].

7. Effects of HMA Modification on Pavement Performance

Modified HMA, referred to as polymer-modified HMA and HMA with the addition of modified binder or additives, is used to improve overall pavement performance in terms of decreased distress. Detailed investigations on the impacts of HMA modification on the properties of binders and mixtures, such as mechanical, physical, and chemical, concerning rutting, fatigue, and thermal cracking, have also gained plenty of interest. The geometry (depth, width, or thickness), parameters (crack area or length), and material (HMA or binder) used in FEM simulations are commonly considered as damage indices, i.e., the key parameters in modelling pavement fatigue distress. This section comprehensively investigates the individual impacts of different HMA modification techniques on fatigue resistance behavior or pavement distresses.

The overview of the dissimilarities between various HMA modification techniques is discussed under a commonly used modification-indicative approach in a later section [41, 42, 62].

Even though various studies have been conducted to assess the performance of HMA modification on distress resistance, a standardized approach to HMA modification has not yet been established. The review of different modification techniques and their comparison based on available case studies to enhance performance is necessary for recognizing the trade-offs between modification parameters and monitoring techniques. Scientific investigations on modified binder performance have pinned the relationship between binder-state properties and overall pavement performance. In addition, to assess the benefits, permanent field experimental studies that consider the extra cost of added materials and necessary long repetitions need to be incorporated. Considering the modification impacts of different binders over short periods instead of whole service lives can lead to a poor solution for achieving sustainability and durability [63, 64].

7.1 Stress Resistance and Rutting

Rutting denotes the permanent and intrusive deformation of pavements and is a major distress type. Rutting is responsible for road accidents and reduces pavement lifespan. Several modifications to HMA have been applied. These include using polymer or rubber modifiers, wax modifiers, and plastic modifiers. Modified mixes are usually able to carry higher compressive stresses and allow more repetitive loadings than conventional mixes [65]. Exciting evidence of modifiers decreasing the amount of rut in asphalt-based pavements has been presented via case studies and observation. Furthermore, an initial relationship between an HMA's composition and its susceptibility to rutting, including the load limits and the number of passes, is an important consideration when designing a modified HMA. Nonetheless, the transport property of the HMA and its effect on performance, in the long run, remains unclear [66-68].

BC modifiers have been proven to be effective solutions in inhibiting rutting in HMA. A polymer-infiltrated asphalt mixture could take higher vertical stresses before beginning complex deformation. Later, LF modifiers were developed to protect against rutting further. The LF modifiers are just as effective as the HLF modifiers and could sustain higher repeated shear stresses. The performance-related specifications redesigned the binder grades imported into the deflection. These results yielded remarkable improvements in the ability of HMA to resist rutting. The HMA mixtures could take much higher repeated shear stresses at the end of this investigation, which means that the newly introduced modifier gave the mixtures even more protection against rutting [69, 70].

Many modifiers have been applied to HMA and have been reviewed. The techniques used include polymers, SBS modified binders, fibers, RAS, and WMA. Most reviewed papers and case studies showed that the modifier had improved the resistance to rutting. BC polymer modifiers, including two types of binders and two simple mixes, were used. They proved that the deflection predictions were closely related to pavement deflection measurements. The pavement deflection was used to correlate the modifier effectiveness, except that a two-coat, two-pass specimen was used. Therefore, a dissection was taken, and the surface of the top was compacted using different asphalt contents for consistency. Furthermore, after the first, second, and third anti-strip, the specimens were compacted with different asphalt equivalently. The resilient modulus or the resilient periodic load was used to construct the prediction model for modifier aggregates for an HMA layout [19, 71, 72].

8. Case Studies and Applications

One of the main modes of failure in flexible pavement include rutting and moisture damage. Different types of distress in pavements can be rectified by employing modified binders in hot mix asphalt. Seven case studies that clearly defined the in-field performance of modified hot mix asphalt were also summarized and presented. From a general perspective, different modification methods were studied, and observations were made towards curing rutting, fatigue cracking, thermal cracking, stripping, and satisfactory performance, being heavily influenced by climatic conditions and/or traffic load. Studies elaborated that no single modification method can address all the issues. It is important to understand that the modification chosen must go hand in hand with the needs of the road based on the geographical location, climatic conditions, and traffic load. Economic benefits were also evaluated in the selected case studies [73-75].

In Wisconsin, there have been two field projects that include the use of polymer-modified asphalt mixtures. Polymer-modified pavements have shown fewer distresses and have required fewer maintenance activities than non-modified pavements. In Wisconsin, poor-performing asphalt pavements can be found in various regions of the state from border to border. A poor-performing pavement is defined as a pavement that is distressed or deteriorating to the extent that maintenance and/or rehabilitation is necessary [76]. Generally, pavement distress occurs in the form of permanent deformation, mainly rutting, thermal and fatigue cracking, as well as moisture damage in terms of stripping, raveling, and potholes. Currently, Wisconsin uses Pavement and Surface Evaluation, Rehabilitation Support, and Instrumentation data to evaluate the state's pavements, make policy recommendations, and assess the need for funds. Stockpiling incurs additional costs in the form of traffic control and reheating hot mix asphalt. It may be of interest in future research, particularly in the use of recycled asphalt pavement hot mix asphalt, to include the temperature of the mixture as well as the existing traffic route to a stockpiled location when evaluating moisture damage [77].

9. Data Collection

The aim of Dimensions is to support academic and scientific research, an online resource containing several research datasets from past projects. Researchers may use it to access a variety of databases that are useful for specialized research. This enables users to do in-depth searches within certain scientific and academic study subfields. These bibliometric methodologies that present previous research are based on strong correlations between shared data. According to the degree of connectivity between the annotated components (authors, nations, references, and keywords) in the scholarly mapping, co-citing papers or authors who appear in the same article, references are grouped based on the map's lines, the founder's nodes, and intensity[78]

10. Analytical Method

Bibliometrics offers scientometric analysis that is dynamic, evaluative, and predictive. Although it came from the field of library and information science, it has now been widely recognized and incorporated for usage in several other fields, particularly for researchers doing quantitative

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studies.it is also widely used by Journals and institutes that depend on scholarly contributions[79, 80]. To carry out the bibliometric process, several programming tools and packages have been developed, including BibExcel, CiteSpace, Pajek, Gephi, VOS viewer, and Histcite. This study created bibliometric maps and visualizations using VOS viewer[81]. Bibliometric network research primarily uses this software, which employs a single framework for both mapping and clustering. VOS viewer may be used to construct three types of visualizations: overlay, network, and density visualizations. Following the elimination of all superfluous documents, 2570 publications were taken out of the Dimensions. Table (1) shows how Dimensions categories are applied to the received documents. About 30.07% and 12.09% of the total appeared in Construction and building materials and the International Journal of Pavement Engineering, whereas the least intriguing subjects were Innovative Infrastructure Solutions and Journal of Transportation Engineering part A Systems. The year of publication of the articles is shown in Figure (1). The graph makes it evident that the number of publications is growing annually at an exponential rate.

Table (1) Documents Detailing the Publications that Obtained Based on Dimension Categories

Categories on the (D)	Record Count	% of 2570
Construction and building materials	808	30.07
International Journal of Pavement Engineering	325	12.09
Road Materials and Pavement Design	291	10.82
Journal of Materials in Civil Engineering	224	8.33
Lecture Notes in Civil Engineering	199	7.40
International Journal of Pavement Research	189	7.03
Materials	125	4.65
Journal of Cleaner Production	91	3.38
Case Studies in Construction Materials	84	3.12
Sustainability	77	2.86
Journal of Transportation Engineering Part B Pavement	65	2.41
Applied sciences	58	2.15
Sustainable Civil Infrastructures	56	2.08
Innovative Infrastructure Solutions	48	1.78
Journal of Transportation Engineering part A Systems	47	1.74

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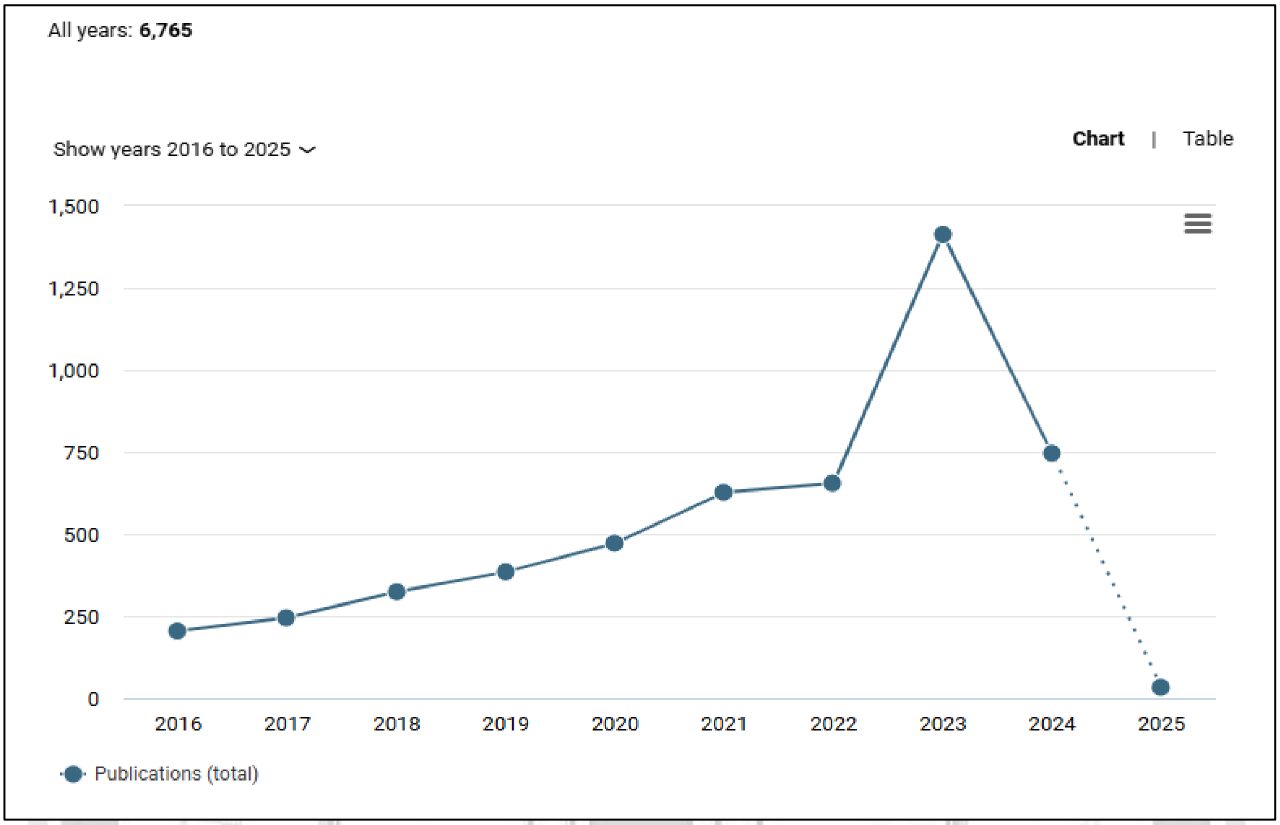

Figure (1) Research Publications Made Year-wise.

10.1. Country and Author Co-authorshipp

Table (2) lists the top 10 contributions made by countries and authors. The United States dominates the number of publications with a total of 767, followed by Egypt (580 publications) and China (96 publications). The top three authors with a high number of publications are Wu and Shaopeng (25 publications), Amin, Muhammad Nasir (17 publications), and Khan, Kaffayatullah (17 publications).

Table (2) The Top Ten Contributions Made by (Countries and Authors) are displayed.

No	Country	F*	Authors	F*
1	United states	767	Xiao, Feipeng,	25
2	China	580	Hajj, Elie y.	21
3	Egypt	96	Mehta,Yusuf	17
4	Malaysia	103	Ali, Ayman	14
5	United kingdom	57	Habbouche,Jhony	13
6	Canada	104	Sebaaly, Peter e.	18
7	Australia	52	Dong, Zishuo	7
8	Germany	29	He, Anzheng	7
9	Saudi Arabia	44	Mohammad,Louay n.	16
10	Jordan	40	Partl, Manfred n.	6

Note: * F= Frequency

10.2. Coo-authorshipo measures

A domain knowledge map of the co-authorship networks of well-known authors could give different institutions useful baseline data to encourage cooperative research teams. Many scholars can also benefit greatly from such material. Researchers can use this data to find new publishers and partners, as well as to compile co-authorship data for editorial teams[82].

Figure (2) shows a map to highlight authors discussing the effect of modified asphalt on road damage due to the failure that occurs on roads as a result of high temperatures or high traffic loads. The elements are represented and classified by circles of different sizes and colours, and the elements are connected by lines that represent the relationships between the elements, and the strongest connection between the elements is through. The thicker lines, in addition to the distance between the elements, show the degree of interconnection. The total strength of relationships with other writers that result from co-authorship is calculated. Those writers who have the most links overall are selected. As a result, there are (19 items),(5 clusters) networks, and (28 links), and the circles are coloured based on the clusters. The network represents the relationships between the authors who discussed the effect of modified asphalt on road damage caused by high traffic loads or extreme temperatures.

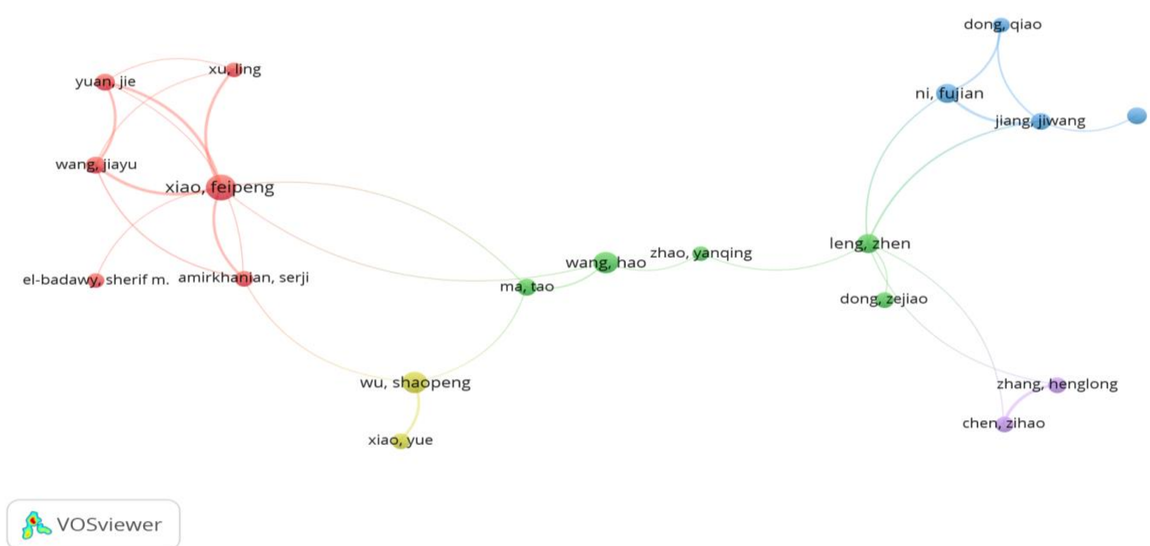

Figure (2) The Author's Network- Visualization Map

10.3. Country

With 13 items, 3 clusters, and 66 links, the network map in Figure (3) shows which nations publish the most research on impact-modified asphalt pavement distresses. The first is the United States, followed by China and Egypt. These nations have offered a substantial body of study that aids in the creation of modified asphalt mixture. China and the United States appear as the most important countries in research related to modified asphalt and are linked to many other countries through strong ties, which reflect the importance of global research.

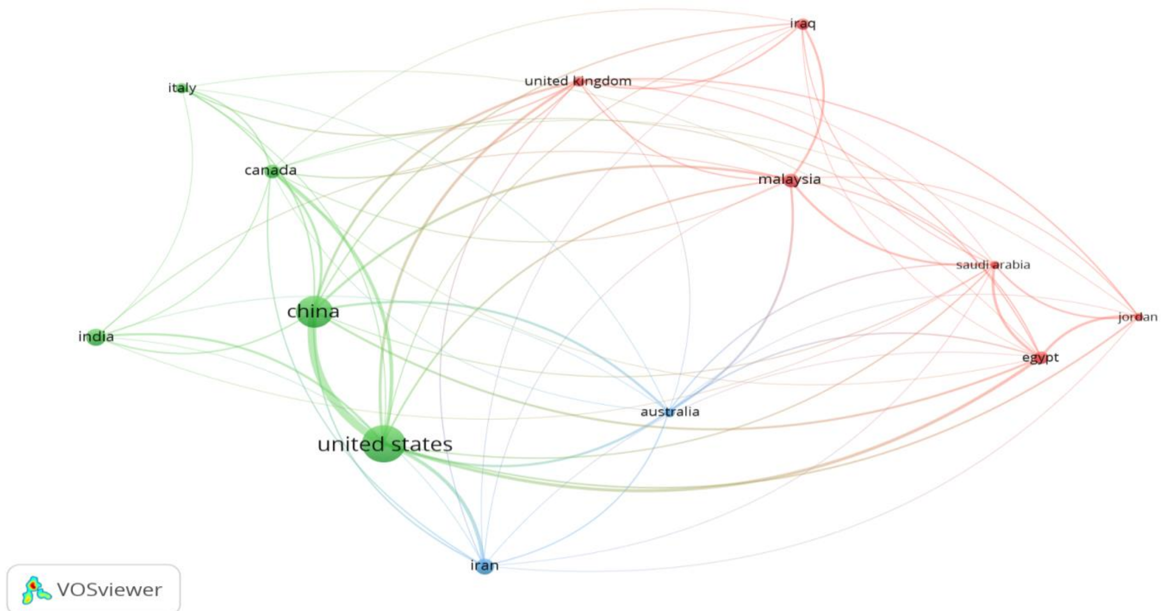

Figure (3) Map of the Countries Visualized Through a Network

10.4. Citation Analysis

By analyzing citation patterns, researchers can assess the performance of research groups and institutions, leading to more accurate evaluations of scientific productivity[83]. The ability to identify document citations and citation groups facilitates the analysis of frequently referred documents to determine the critical research domain [84].

10.5. Using document ass a citation- unit

With 13 items, 3 clusters, and 66 links, the network map in Figure (4) shows which nations publish the most research on the impact of modified asphalt on pavement distress,The study by Yildirim (2007) represents a focal point, as it is the largest and most closely linked to the other nodes, which indicates that it is a major reference study on modified asphalt, while the recent directives that represent the yellow nodes, such as Kheradmandi 2022, indicate more recent studies that often focus on new developments that tend to explore new materials or polymers to improve the performance of asphalt.

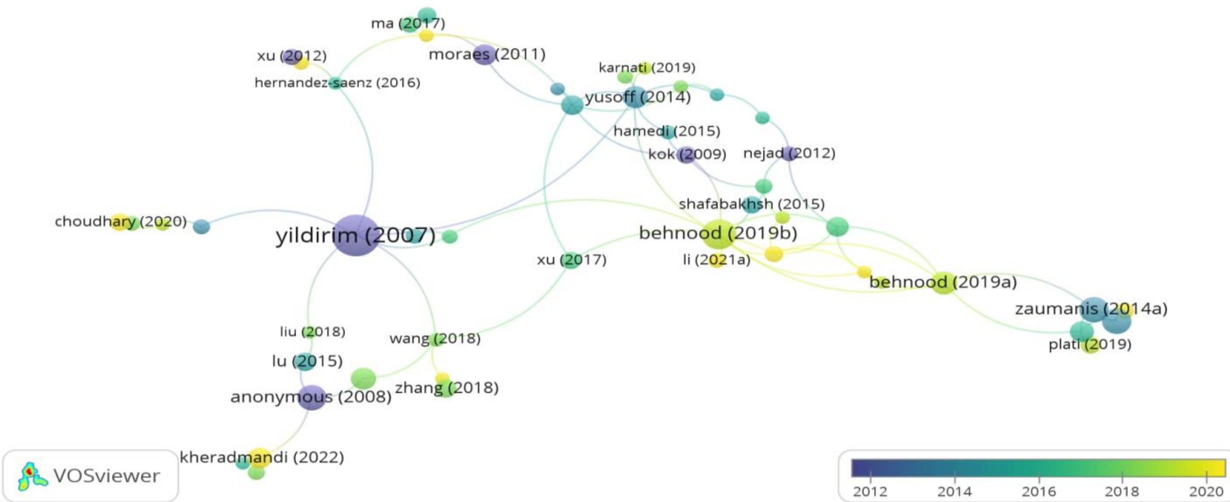

Figure (4) Citations Network – Document

10.6. Citation Analysis of Scientific Journals

A metric analysis was conducted based on the titles of scientific journals and a study of the influence of the journals and their relationship to each other regarding modified asphalt. Out of the 437 sources, only 78 showed connections between them. The timeline shows how the influence of the journals has changed over time, with the journals in blue colours being the most active in the earliest periods, followed by green and yellow, indicating the most recent activity see Figure (5).

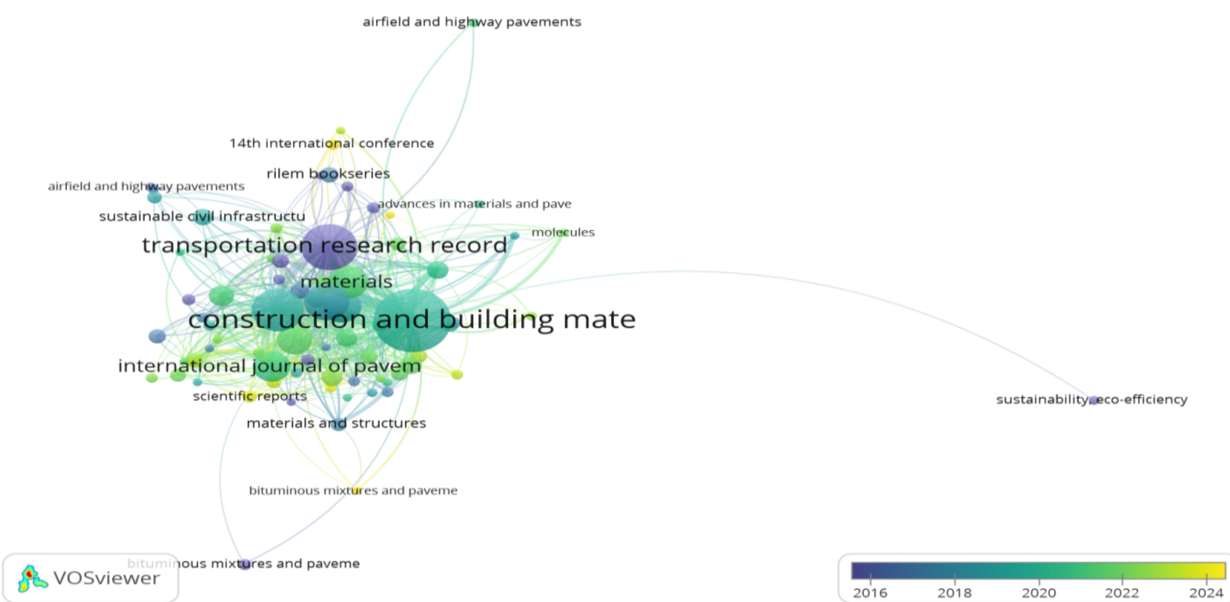

Figure (5) Citation Network – Source

10.7. Using Organizations as a Unit of Citations Analysis

Table (3) displays the most important universities and research institutions. The most prominent of these institutions is Chang An University. It is considered the most productive and influential university in this field in terms of the number of documents: 96, citations: 1,521, and a link strength of 143. Southeast University shows a great influence: the number of documents: 94, the citations: 1,520 and the strength of the links: 120, as it shows the existence of research cooperation. It is noticeable among universities, especially among Chinese universities such as Chang An University and Southeast University, and the timeline shows how it has developed research over the years, as scientific activity was strong and continuous between 2018 and 2021, as shown in Figure (6).

Table (3) Most Organization

NO	Organization	Documents	Citations	Total link strength
1	chang an university	96	1521	143
2	southeast university	94	1520	120
3	tongji university	66	1616	116
4	wuhan university of technology	41	881	108
5	harbin institute of technology	33	470	67
6	Texas a&m university	55	1354	63
7	Amirkabir university of technology	38	1179	59
8	iran university of science and technology	44	1300	52
9	Iowa stste university	33	386	41
10	Mansoura university	36	557	39

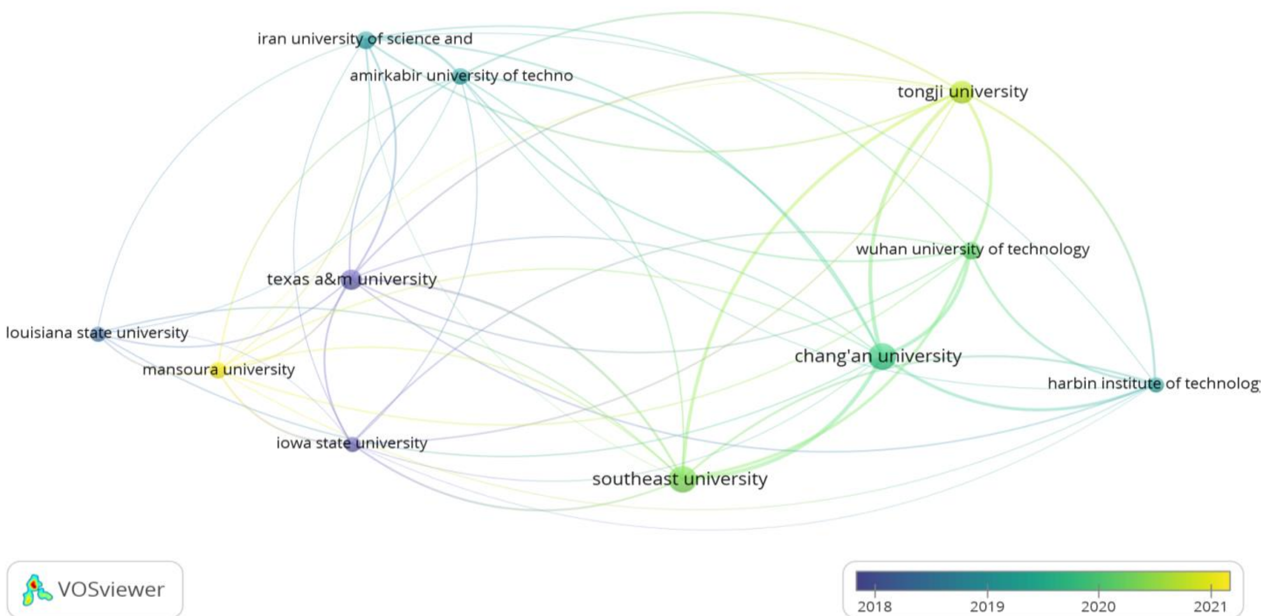

Figure (6) Citation- Network – Organization

10.8. Co-citation Examination

Co-citation analysis is a major tool in scientometric studies, especially within the statistics community, since the study highlights the use of co-citation networks to estimate authors' research interests and their evolution over time [85]. In addition, it stresses the importance of author co-citation analysis (ACA) in scientometric research. It highlights the value of co-citation in comprehending the connections and significance of scholarly work and suggests strategies for choosing authors based on citation metrics[86].

10.9. Co-citation Cited Reference

Out of 31052 citations, 20 satisfied the criterion, making twenty the least number for the selected referenced source. Figure (7) the most cited and significant references are highlighted in yellow, indicating that they serve as a foundation for numerous studies and are, therefore, pivotal references. Conversely, the less frequently cited and influential references are highlighted in blue. This illustrates the strength of the links between references.

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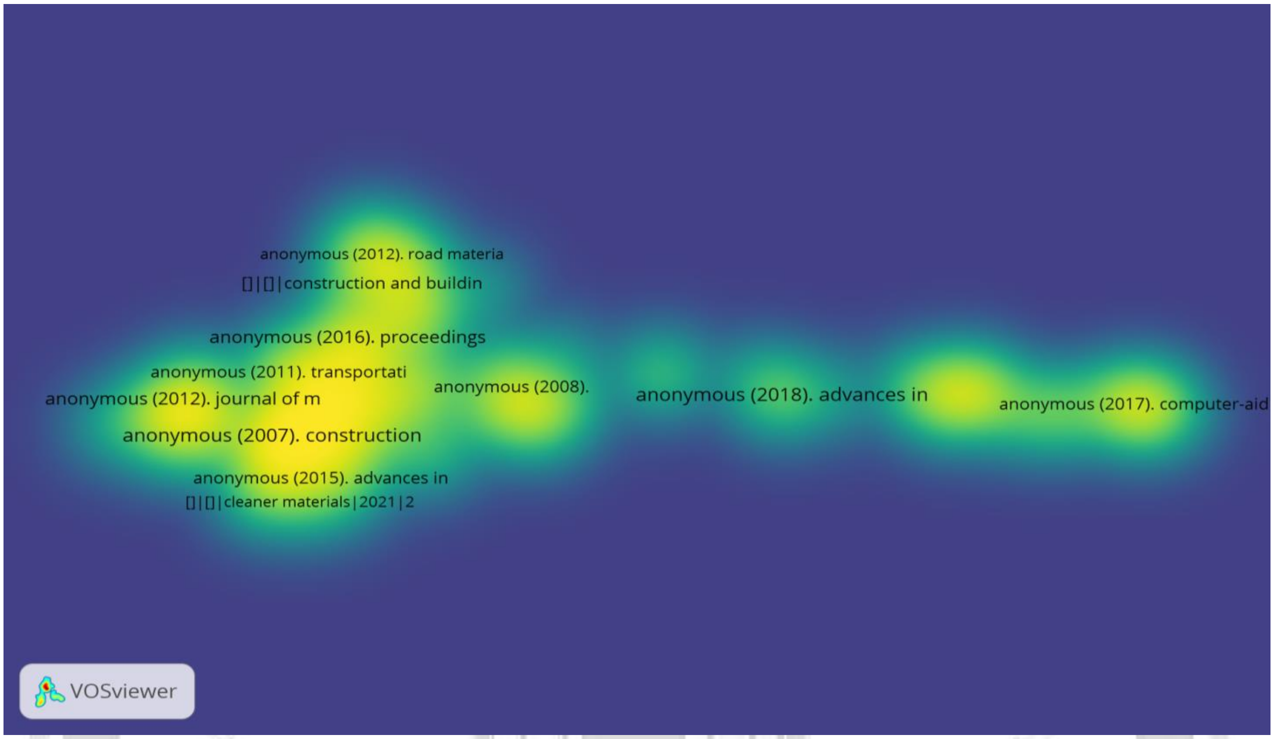

Figure (7) Co-citation Cited References Density Visualization

10.10. Co-citation Source

Just 265 out of 4057 numbers were deemed to be the minimum, 20, as per the criteria. As seen in Figure (8), a net including 7 major clusters and 25615 linkages was created. Construction and building materials are considered the most influential source in the field, as it covers multiple aspects such as the properties of modified materials and performance tests. The Transportation Research Record focuses on applications of modified asphalt in transportation and infrastructure. The Journal of Cleaner Production may refer to research related to sustainability and the use of recycled materials in asphalt.

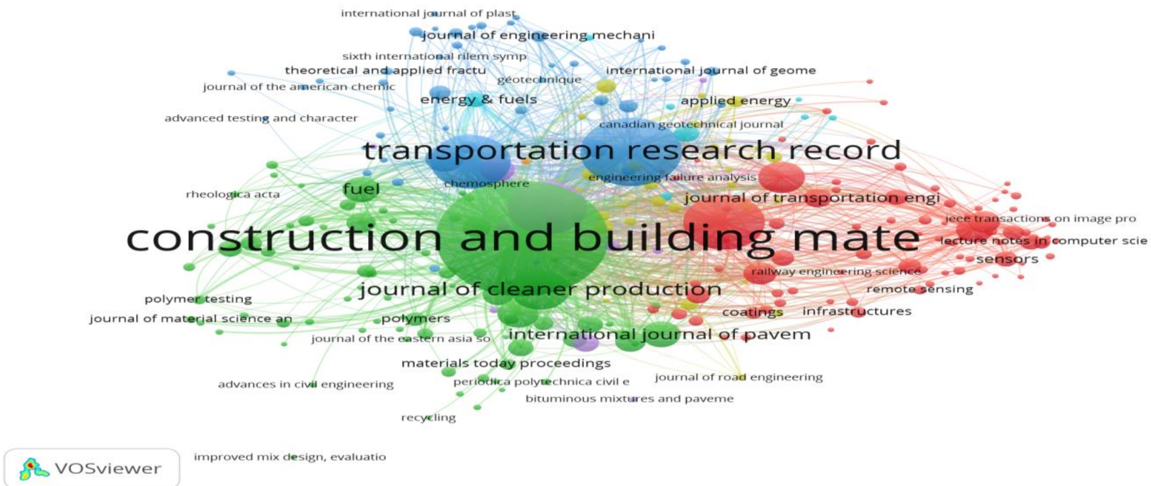

Figure (8) Co-citation – Source

11. Conclusions

The study concluded that modifying asphalt mixtures using polymers clearly improves their resistance to various defects such as thermal cracking, rutting, and peeling. Bibliometric analysis also showed that there is a growing interest in this research field, especially in major industrial countries, where most scientific production is focused on improving the performance of asphalt pavements and enhancing their sustainability. After reviewing the literature and analyzing data using VOS viewer software on modified asphalt and its resistance to pavement distress, the following key conclusions can be drawn:

- Modified asphalt has proven effective as a solution for improving pavement performance and resistance to various defects, such as rutting, stress cracking, and thermal cracking. By incorporating polymers, recycled rubber, and other additives, modified asphalt offers improved durability, greater flexibility, and better resistance to harsh weather conditions. These improvements contribute to longer pavement life, reduced maintenance costs, and enhanced sustainability in road construction projects.
- Through bibliometric analysis using the VOSviewer tool, this study identified the most prominent researchers in the field of modified asphalt and its resistance to various pavement defects. The results highlighted significant contributions, collaborative networks, and the level of interaction within the scientific community. Prominent researchers in this field include Xiao Feiping, Haji Ali Y, Mehta Yusuf Ali, Ayman Haboush, Johnny Sebali, and Peter E. In addition, the analysis identified leading countries that disseminated knowledge on the subject, including the United States, China, Egypt, Malaysia, and the United Kingdom. The study also revealed that several major universities are collaborating on research related to modified asphalt mixtures, including Chang'an University, Southeast University, Tongji University, and Wuhan University of Technology.

- This study provides a valuable framework for researchers seeking to understand the fundamental principles of modified asphalt mixtures. To achieve optimal resistance to pavement defects, an improved HMA-PCC system design that balances performance, sustainability, and cost is required. The adoption of modified asphalt must be based on a comprehensive assessment of its long-term benefits. Furthermore, continuing education and professional development for engineers, researchers, and practitioners in the field are essential to keep abreast of the latest developments, challenges, and innovations in the field.

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تعديل الخلطات الاسفلتية الساخنة ومقاومتها لعيوب الرصف: تحليل متري علمي ومراجعة ببليومترية

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الخلاصة

شهدت تقنيات الأسفلت الساخن (HMA) تطورات ملحوظة في هندسة الرصف، حيث عززت التعديلات الحديثة خصائصه الريولوجية وزادت من مقاومته للتشقق والتجعد والتلف الناتج عن الرطوبة. ساهمت هذه التحسينات في إطالة عمر الرصف وخفض تكاليف الصيانة، مما جعل HMA خيارًا أكثر استدامة للبنية التحتية. وقد أظهرت خلائط الأسفلت المعدلة بالبوليمر والمطاطية أداءً متفوقًا مقارنةً بالإسفلت التقليدي، مما يوفر متانة محسنة في ظل أحمال مرورية ثقيلة وظروف بيئية قاسية. بالإضافة إلى ذلك، فإن استخدام المواد المعاد تدويرها، مثل المطاط من الإطارات المهملة، يحسن المتانة مع تقليل التأثير البيئي. تُستخدم هذه التقنيات على نطاق واسع في مشاريع البنية التحتية، بما في ذلك الطرق السريعة والجسور والأنفاق والمناطق الصناعية وساحات انتظار المطارات، مما يؤدي إلى تحسين الأداء العام وخفض تكاليف الصيانة. ستحلل هذه الدراسة اتجاهات البحث حول آثار خلائط الأسفلت المعدلة على أداء الرصف باستخدام قاعدة بيانات Dimensions وبرنامج VOS Viewer. وعلاوة على ذلك، ستحدد الدراسة البلدان والمؤسسات المساهمة الرئيسية، فضلاً عن فحص شبكات التعاون البحثي بين العلماء، بهدف تقديم رؤى تدعم تطوير وتعزيز خلطات الأسفلت المعدلة لتحقيق أداء متفوق واستدامة أكبر.

الهدف من الدراسة

تهدف هذه الدراسة إلى استكشاف حدود الأبحاث الحالية المتعلقة بخلطات الأسفلت المعدلة، والتطورات الحديثة، واتجاهات البحث الناشئة باستخدام الخرائط المعلوماتية والتحليل الببليومتري. على الرغم من اعتماد منهج المراجعة الكمية، إلا أن هذه الأدوات التحليلية لا تستطيع إزالة جميع التحيزات والقيود الموجودة في الدراسات التقليدية. تُعد هذه المراجعة من أوائل الدراسات التي طبقت التحليل الببليومتري على نطاق واسع ضمن حدود البيانات المتاحة، مما يُمكّنها من تصنيف أحدث الابتكارات في توصيف خلطات الأسفلت المعدلة بدقة ووضوح أكبر .

طريقة العمل

الهدف من (Dimension) هو دعم البحث الأكاديمي والعلمي، وهو مورد عبر الإنترنت يحتوي على العديد من مجموعات البيانات البحثية من المشاريع السابقة. يمكنك استخدامه للوصول إلى مجموعة متنوعة من قواعد البيانات المفيدة للبحث المتخصص. يمكّن هذا المستخدمين من إجراء عمليات بحث متعمقة في بعض المجالات الفرعية للدراسة العلمية والأكاديمية. تستند هذه المنهجيات الببليومترية التي تقدم أبحاثًا سابقة إلى ارتباطات قوية بين البيانات المشتركة. وفقًا لدرجة الاتصال بين المكونات المشروحة (المؤلفين والأمم والمراجع والكلمات الرئيسية) في رسم الخرائط العلمية يتم تجميع الاوراق او المؤلفين الذين يظهرون في نفس المقالة على اساس خطوط الخريطة, وعقد المؤسس والشدة.

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الاستنتاج

خلصت الدراسة إلى أن تعديل خلطات الأسفلت باستخدام البوليمرات يُحسّن بشكل واضح مقاومتها لمختلف العيوب، مثل التشقق الحراري، والتجعد، والتقشير. كما أظهر التحليل الببليومتري تزايد الاهتمام بهذا المجال البحثي، لا سيما في الدول الصناعية الكبرى، حيث يُركز معظم الإنتاج العلمي على تحسين أداء رصف الأسفلت وتعزيز استدامته. بعد مراجعة الدراسات السابقة وتحليل البيانات باستخدام برنامج VOS Viewer حول الأسفلت المُعدّل ومقاومته لعيوب الرصف، يُمكن استخلاص الاستنتاجات الرئيسية التالية :

- أثبت الأسفلت المعدل أنه حل فعال لتعزيز أداء الرصيف ومقاومة الضائقة المختلفة، مثل التشقق والتعب والتشقق الحراري. من خلال دمج البوليمرات ومطاط الفتات والمواد المضافة الأخرى، يوفر الأسفلت المعدل متانة ومرونة ومقاومة محسنة للظروف الجوية القاسية.يساهم استخدام الأسفلت المعدل في إطالة عمر خدمة الرصيف، وخفض تكاليف الصيانة، وتحسين الاستدامة العامة في بناء الطرق. تم العثور على أهم الباحثين في مجال الأسفلت المعدل ومرونته في مواجهة محن الرصيف باستخدام أداة VOS viewer. تم التأكيد على مساهماتهم وعلاقاتهم ودرجات التعاون داخل المجتمع العلمي من خلال التحليل.: شياو، فيبينغ، الحج، ايلي واي، ميهتا، يوسف علي، أيمن، حبوش، جوني سبعلي، وبيتي اي. بالإضافة إلى ذلك، حددت أي بلد، مقارنة بالولايات المتحدة والصين ومصر وماليزيا والمملكة المتحدة، أهم بلد في انتشار المعرفة حول هذا الموضوع. الجامعات تعمل معًا من أجل إجراء أبحاث على خلطات الأسفلت المعدلة تشمل: جامعة تشانغ الجامعة الجنوبيه الشرقيه. جامعة تونغجي وجامعة ووهان للتكنولوجيا. نتيجة لذلك، توفر هذه الدراسة مسارًا للأكاديميين لفهم المفاهيم الأساسية المتعلقة بخلائط الأسفلت المعدلة. لذلك، يمكن تحقيق مقاومة ضائقة الرصيف من خلال التصميم الأمثل لنظام HMA-PCC المعدل. نظرًا لأن قرار استخدام HMA المعدل هو قرار متوازن، فإن أفضل تطبيق هو القرار الذي يمكن أن يثبت الاستدامة وفعالية التكلفة. يجب توفير التعليم المستمر لمهندسي الأرصفة والباحثين والممارسين لإطلاعهم على أحدث النتائج والاحتياجات والتطورات في هذا المجال.

الكلمات الداله:- أضرار الرصف, الخلطات الاسفلتية المعدلة, الخلطات الاسفلتية الساخنة, تعديل البوليمر , التحليل البليومتري