Malaysian Journal Of
Civil Engineering

A COMPREHENSIVE REVIEW OF THE USE OF NEUTRAL CARBON AND BIO-OIL WASTES ON WARM MIX ASPHALT CONCRETE

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Article history
Received
29 November 2023
Received in revised form
21 January 2024
Accepted
28 January 2024
Published online
31 March 2024

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Graphical abstract

Modified Warm Mix Asphalt Pavement

Abstract

Waste materials can be used to produce cement concrete, asphalt concrete, block concrete, and other construction materials. This has been known for more than 30 years in the field of civil engineering. To allay ecological concerns, several nations are currently researching the reprocessing of neutral carbon and bio-oil wastes (NC&BoWs). These wastes are sustainable, but because of their large volume of landfill disposal, which has detrimental effects on the ecosystem and its inhabitants, they are starting to become quite worried for the ecosystem. Therefore, this study provides a comprehensive review of the use of NC&BoWs on warm mix asphalt (WMA) concrete to lessen our worries about the environment. Numerous investigations have been conducted to enhance various WMA technologies. These three technologies such as foaming, chemical, and organic enhance the structural behavior of WMA concrete and lower the viscosity of the asphalt binder. A bibliometric analysis shows that only 26 out of the 168 articles related to this study were published by Scopus between 2012 and 2023. Full-length articles accounted for 100.0% of Scopus publications, and it seems that not a single review article was accepted and published by Scopus. Based on the subject area, the fields of engineering, materials sciences, and physics and astronomy published 50.0%, 43.5%, and 6.5% of the Scopus articles, respectively. Consequently, the findings suggested that further reviews are necessary to verify NC&BoWs' ongoing efficacy in WMA concrete.

Keywords: Neutral carbon waste, bio-oil waste, WMA concrete, WMA technologies, warm mix additives.

Abstrak (BM)

Bahan buangan boleh digunakan untuk menghasilkan konkrit simen, konkrit asfalt, konkrit blok, dan bahan binaan lain. Ini telah dikenali selama lebih dari 30 tahun dalam bidang kejuruteraan awam. Untuk meredakan kebimbangan ekologi, beberapa negara sedang meneliti pemprosesan semula sisa karbon dan bio-minyak neutral (NC&BoWs). Sisa-sisa ini mampan, tetapi kerana jumlah pelupusan tapak pelupusan yang besar, yang mempunyai kesan buruk terhadap ekosistem dan penduduknya, mereka ar. Oleh itu, kajian ini memberikan kajian menyeluruh mengenai penggunaan NC &BoW pada konkrit asfalt campuran panas (WMA) untuk mengurangkan kebimbangan kita tentang alam sekitar. Banyak penyiasatan telah dijalankan untuk meningkatkan pelbagai teknologi WMA. Ketiga-tiga teknologi seperti berbuih, kimia, dan organik meningkatkan tingkah laku struktur konkrit WMA dan menurunkan kelikatan pengikat asphalt. Analisis bibliometrik menunjukkan bahawa hanya 26 daripada 168 artikel yang berkaitan dengan kajian ini diterbitkan oleh Scopus antara 2012 dan 2023. Artikel panjang penuh menyumbang 100.0% daripada penerbitan Scopus, dan nampaknya tidak ada satu artikel ulasan yang diterima dan diterbitkan oleh Scopus. Berdasarkan bidang subjek, bidang kejuruteraan, sains bahan, dan fizik dan astronomi diterbitkan 50.0%, 43.5%, dan 6.5% artikel Scopus, masing-masing. Oleh itu, penemuan mencadangkan bahawa ulasan lanjut diperlukan untuk mengesahkan keberkesanan NC&BoWs yang berterusan dalam konkrit WMA.

Kata kunci: Sisa karbon neutral, sisa bio-minyak, konkrit WMA, teknologi WMA, bahan tambahan campuran hangat.

1.0 INTRODUCTION

For more than 30 years, it has been known that waste materials (rubber) from damaged tires can be used in some civil engineering projects. These materials include cement concrete, asphalt concrete, and crushed earth structures [1]. The accumulation of waste tires is a global ecological concern since the globe produces $1.5x10^9$ tonnes of garbage tires annually [1]. These waste materials are not recyclable and, if deposited in landfills and stocks, are known for discharging poisonous chemicals into the ecosystem, behaving as refinement grounds for leeches, and powering inextinguishable fires [1]. Firoozi et al [2] utilize plastic waste bottles and shattered glass to improve the flexural and strength characteristics of concrete. In the building industry, using these recycled materials could result in lower costs, less material needed, cheaper labor, and improved resistance to abrasion. Repurposing used tires in the civil engineering industry is a financially and environmentally responsible method of disposal [1].

According to Syarif et al [3], Waste material anxiety is currently a global concern that will undoubtedly hurt the environment. Reprocessing waste materials is still being studied in several countries to allay concerns about the environment. These waste products (carbonized rice husk, coal bottom ash, biomass ashes, etc.) improve the performance of hot mix asphalt (HMA), save building costs, protect the environment, and preserve natural resources [2][3]. Even though the neutral carbon and bio-oil wastes (NC&BoWs) have small particle sizes and gradations, some research has been done on their use in different paving combinations [6][7]. Salleh et al [8], state that there is a good chance the extracted lignin will be converted into monomeric aromatic by-products, which might be used as building blocks for bio-oils, biochemical synthesis, biomaterials, sewer-water treatment, and the nutrition industry. According to Zulkati [9] various fillers have a variety of profound effects on various asphalt concrete qualities. The various filler material components have an impact on the various properties of asphaltic concrete [10][11]. Filler materials include imported fillers like fly ash, hydrated lime, and furnace slag, as well as common fillers like dolomite, granite, cement, volcanic ash, basalt, andesite, caliche, etc. [12][13].

The asphalt industry is more than ever challenged with inadequate and progressively expensive provisions for asphalt materials [14][15]. Ash generated by the burning of wood biomass, which is used to produce power and heat, is hypothetically valued waste material [13][16]. The improved asphalt industry has resulted in a significant capacity of waste products that must be deposed off, posing grave ecological problems [17][18][19]. To reduce the disposal problems associated with the production of waste materials, recycling of these materials, for example, sugarcane bagasse ash (SCBA), should be carried out to provide suitable replacement materials for the construction of pavements [20][21]. Nguyen et al [22] use chicken egg-shell powder as a substitute coagulant. The use of this reused material leads to the enhancement of the textural characteristics of tofu.

According to a study by Wang et al [23], bio-oils based such as soybean oil, straw oil, and castor oil significantly enhanced the repossession rate of aged asphalt, reduced its non-repossession creep compliance, and successfully improved plasticity resilience and its everlasting deformation resistance. The researcher further discovered that vegetable oil and gutter oil produced by aged asphalt have significantly small frequency sensitivity and the most promising effect on the resistance to crack. However, if NC&BoWs are appropriately managed, the utilization of these materials would not only be economical but would also create income for foreign exchange as well as a decrease in ecological effluence. Rice straw ash (RSA) is one of the agro-waste materials that produce the majority of the ecological issues [24]. The use of waste products such as agro-waste groundnut shells in the sustainable construction of concrete requires high demand for pavement and building materials [25][15]. This resulted in the high cost of the state-of-the-art pavement materials with an introduction and a state-of-the-art design technique for sustainable pavement materials (groundnut shell ash) for the stabilization of reclaimed asphalt pavement [21][26][27]. Furthermore, this has led to some studies on the use of NC&BoWs in WMA concrete as a tool for reducing environmental disposal problems, thereby contributing to the management and reprocessing of waste products [17][28][29].

Warm mix asphalt (WMA) refers to technologies that can reduce the production temperature of asphalt mix compared to conventional HMA [30]. Although the accurate amount of this temperature reduction varies from one introduction to the other, it is typically concluded that WMA technologies can reduce the WMA production temperature by 35 ^{0}C - 55 ^{0}C (63 ^{0}F - 95 ^{0}F) compared to conventional HMA [30]. This reduction in the production temperature leads to minor power consumption and reduced emissions of greenhouse gases or other negative gases to the atmosphere [31]. Consequently, the utilization of WMA is a beneficial mechanism for mixing waste products with bitumen production more frequently, a finish that has in potential to attain a justifiable pavement construction [21]. WMA technology is defined as a potential and justifiable pavement construction due to its economic and environmental benefits [32]. To eradicate the environmental difficulties associated with the high manufacture and compaction temperatures when using recycled asphalt pavement (RAP), WMA technologies can be applied [21][33]. Several WMA technologies use warm mix additives or foamed asphalt binders to decrease the mixing and compaction temperatures of asphalt roadways which harshly disturb the environment [21][33].

Duarte and Faxina [34] have revealed that the integration of post-consumer plastic into asphaltic concrete blends by the wet and dry methods might lead to an enhancement in the behavior of asphalt roadways, which supports the extenuation of failures such as continuous deformation, thermal cracking, and fatigue cracking. Plastics are generally used in total aspects of everyday life [35]. Deficient suitable methods for waste management, a large production of plastic waste may lead to the majority of global environmental issues [35]. The most frequent categories of plastic wastes in the United States municipal solid waste stream comprise polyvinyl chloride, polyethylene terephthalate, ethyl vinyl acetate, polystyrene, polypropylene, high-density polyethylene, and low-density polyethylene [35]. To provide a sustainable solution to these plastic wastes, HMA is considered the perfect choice to recycle plastic wastes in high-value utilizations due to its high practice in pavement construction [35].

According to Huang et al [36], municipal solid waste burning fly ash comprises heavy metals and carbon-based contaminants, which exert a vast menace to human well-being and ecological protection. The cumulative demand for non-recyclable resources for instance bitumen is an important issue in the asphalt industry [37]. Flexible roadway mostly depends on and consumes a huge amount of bitumen, which has developed a substantial issue in terms of ecological sustainability and financial viewpoints [37]. Hence, scholars struggle to discover other solutions, such as using NC&BoWs to modify bitumen to extend the lifecycle of flexible roadways. The eco-friendly aquaphobic anti-icing fillers have added countless prominence because of the cumulative demand for green ecology [38]. The purpose of this study is to provide a comprehensive review of the use of NC&BoWs on WMA concrete for an eco-friendly perspective. The conversion of wastes into wealth and pollution into solutions to save a substantial number of waste products and pave the way for acceptable development is the novelty of this study.

The bibliometric analysis reveals that only 26 out of the 168 articles were published by Scopus between 2012 and 2023. Full-length articles accounted for 100.0% of Scopus publications, and it seems that not a single review article was accepted and published by Scopus. However, to fill the bibliometric analysis's missing gap, this study, therefore, provides a comprehensive review of the use of NC&BoWs on WMA concrete from an eco-friendly perspective. In addition, this study also includes a thorough assessment of NC&BoWs, their various properties, and the effects of other NC&BoWs on WMA concrete.

2.0 UTILIZATION OF NC&BoWs

The existing advancements in the field of biomedical have been unusually attained in the previous years, particularly in the production of nanomaterials such as carbon nanotubes that have numerous applications [39]. Hatta et al [39] reported that carbon nanotubes exhibit exceptional physical, chemical, and electrical characteristics, and these extraordinary characteristics have resulted in the advancement of carbon nanotubes-based products in the field of biomedical. The utilization of NC&BoWs such as coal bottom ash, waste cooking oil, waste engine oil, sawdust, marble dust, cashew nut shell oil, cigarette butts, carbonized wood particles, rice husk, hydrated lime, groundnut shell, crushed glass, plastics, municipal solid waste incinerator, sugarcane bagasse, wooden charcoal, steel slag, benzene soluble fraction, coconut shell, crumb rubber, oxidant, zycosoil, scrap tires, paver dust, stone dust, limestone, dates seed, ceramic waste, coal fly ash, cow bone ash, lumber ash, extender, palm oil fuel ash, etc. in the asphalt industry have been found as sustainable materials for warm mix asphalt (WMA) mixtures [6][40][41].

Disposal of NC&BoWs directly into the ecosystem can cause ecological problems [42][43]. Likewise, developed nations have rigorous ecological guidelines, whereas several underdeveloped nations have almost no guidelines to manage the ecosystem against effluences [44][45][46]. Waste products (marble and red mud) can be used to produce state-of-the-art products that encourage the effective use of natural products and defend the ecosystem from the disposal of waste materials [47][48]. This required many state-of-the-art study efforts in developing nations to focus on the direction of using inexpensive and readily available conservative materials, such as industrial and agricultural waste products, to reduce construction costs [49][50]. Additionally, the substantial increase in the annual production of these wastes, along with the necessity for their eco-friendly disposal, has zoomed interest in using these wastes (wood waste and bottom ashes) as replacement materials in the pavement industry [51][32][52]. The use of waste materials for sustainable construction would not only be economical but might also yield substantial incomes from foreign exchange and reduction of environmental contamination [32][53][54]. Figure 1 shows the transformation behaviors of three types of carbons.

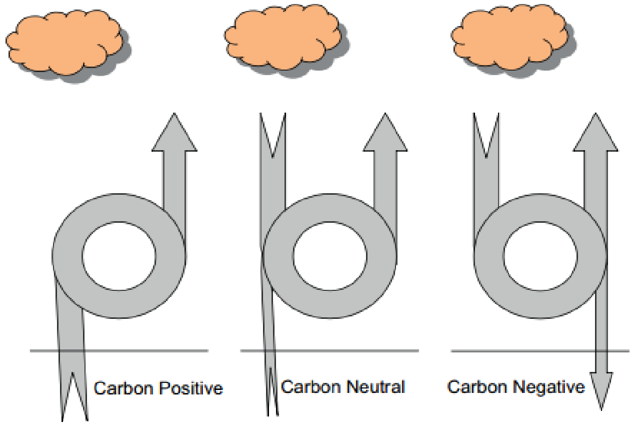


Figure 1 Transformation behaviors of different carbons [55]

However, sustainable utilization of economical and replacement wastes (red mud and slag) in pavement construction and the enhancement of thermal properties of asphalt concrete has become an extensive technique in the asphalt industry, which indicates the better-quality performance of pavement [15][56]. Therefore, this contributed immensely to the efforts being made in the construction industry to utilize waste products instead of discarding or burning them. Municipal, industrial, and agricultural solid products are cases of such wastes [57][58]. Several transportation agencies are studying the potential, ecological suitability, and behavior of using waste material (waste cement dust) as a mineral filler or replacement agent in pavement construction [59][60]. Consequently, reprocessing NC&BoWs into valuable goods has become a general solution to waste disposal problems (pollution to solution approach) [61][62][63]. Figure 2 shows the transformation behavior of the neutral carbon cycle generated by the power plants sector.

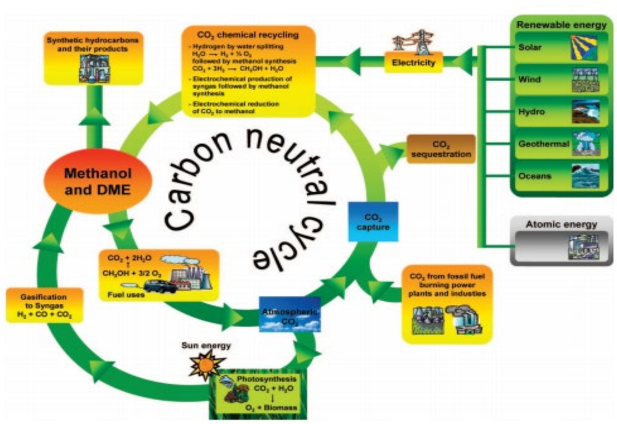


Figure 2 Transformation behavior of carbon neutral cycle [64]

2.1 Types of NC&BoWs

Several studies have been made on the utilization of different types of plastic waste for the construction of pavement in different countries [21][61][65][66][67][68]. Supit and Priyono [65] studied the use of modified plastic waste on the permeable concrete block integrating fine aggregates. The researchers discovered that the use of coarse aggregates produced from this material (plastic waste) is a promising solution for the management of waste plastic for permeable roadways such as pedestrian traffic and lightweight roadways. The huge volume of neutral carbon and bio-oil wastes (NC&BoWs) produced from the operation of wood processing in many countries creates the difficult potential for the use of wood waste as construction materials [51]. Therefore, these NC &BoWs comprising coal bottom ash (CBA), waste cooking oil (WCO), waste engine oil (WEO), sawdust ash (SDA), rice husk ash (RHA), groundnut shell ash (GSA), sugarcane bagasse ash (SCBA), coconut shell ash (CSA), dates seed ash (DSA), and others. Comprehensive reviews of these NC&BoWs are discussed in subsections.

2.1.1 Coal Bottom Ash (CBA)

The usage of coal bottom ash (CBA) possibly conserves the global economy in future construction and may reduce the ingestion of natural products [69]. Ksaibati [70] revealed that substituting a reliable amount of fine aggregate with CBA could show similar results to conventional hot mix asphalt (HMA) for the pavement-wearing layer. Substitution of fine aggregate with CBA (10% and 20%) by the total mass of aggregates for binder and wearing courses does not distress rutting resistance, tensile strength, and minor temperature cracking [71][72][73]. Ksaibati et al [70] revealed that HMA blends with Wyoming bottom ash (15%) substituted with granite and mineral aggregate showed similar results when conserved with hydrated lime. Chen et al [74] investigated the engineering and ecological assessment of municipal solid waste bottom ash (MSWBA) as an aggregate substitute used for asphalt concrete. It was discovered that there is a linear decrease in the tensile strength ratio with an increase in MSWBM dose.

Kavussi et al [75] studied the moisture susceptibility of warm mix asphalt (WMA) as an aggregate replacement. The outcomes of the study showed that asphalt mixtures with CBA and lime had better moisture resistance. Mohammed et al [76] studied a widespread review of the use of CBA as a pavement material in the construction industry. The results of the review suggested that CBA is an optimistic material for road construction.

Singh [77] investigated the influence of CBA as a partial replacement for sand on various properties of concrete. The outcome of the investigation showed that CBA can be utilized in a variety of production and construction usages. CBA is used as landfill material and as binder layer material in road construction [77]. Nowadays in America, CBA is mostly used for the following applications: (i) structural fill material, (ii) readymade soil materials, (iii) drainage island, (iv) backfill material, (v) base, and sub-base material, (vi) traction/abrasives, and (vii) aggregate for asphalt concrete (a mandatory work). Figure 3 shows the original and the crushed CBA.

(a). (b).

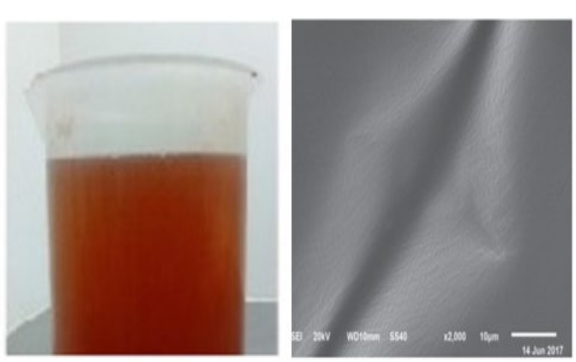
Figure 3 (a). Original CBA; (b). crushed CBA [78]

2.1.2 *Waste Cooking Oil (WCO)*

Waste cooking oil (WCO) is a bio-oil waste that can be classified into two major classes. The first class is the "yellow grease", which comprises fatty-free acids (FFAs) not greater than 15%, and the second class is the "brown grease", which comprises FFAs greater than 15% [79]. The structure of cooking oil is varied by the oxidation reaction through distinctive approaches after an open-air frying technique [80]. A study by Zhang et al [81] discovered that an enhanced quality WCO to rejuvenate bitumen is anticipated to have a minor acid value in milligrams required to neutralize one gram of WCO.

A study conducted by Azahar et al [82] showed that WCO can change the physical properties of asphalt when combined with the bitumen mixtures, resulting in a substantial decrease in fatigue cracking and development in mechanical characteristics of the binder. However, high WCO doses in the warm mix also pose grave impacts on the service life and mechanical performance of block asphalts. Undeniably, additional thorough investigations are needed in this area.

A study conducted by Yel-shorbagy [83] suggested WCO as a rejuvenator that enhances unprocessed pavement and reinstates its virgin characteristics. Zargar et al [84] also recommended that the integration of WCO in the pavement is a credible solution to environmental pollution. Yet, with its wide range of anticipated environmental and functional benefits, its application is still partial. Figure 4 shows the neat and rejuvenated WCO.



(a). (b).

Figure 4 (a) Neat WCO [85]; (b) WCO-modified binder [83]

Asli et al [86] and Chang [87] studied the potential of utilizing WCO as revived bitumen binder and probable green solvent, respectively. The results of these studies showed that the physical and rheological properties of aged asphalt pavement could virtually reinstate its state-of-the-art condition with an increase in WCO dose. Table 1 presents the physical properties of WCO.

Table 1 Physical properties of WCO [88]

S/N	Property	Unit	WCO
1	Density	g/cm^3	0.91
2	Flash point	^{0}C	265
3	Viscosity @ 40 ^{0}C	cP	73

Asli et al [86] stated that the slight elements of WCO can improve the physical characteristics of revived aged bitumen. However, Sun et al [89] discovered distress in resistance to the pavement due to increased WCO dose. Slight elements in WCOs are stress-free to react and volatilize in aged bitumen, and polymerization may occur in modified polymer asphalt. The evaluation of WCO-based asphalt is quicker than fuel asphalt when vulnerable to unwarranted temperatures [90]. To recap, Fini et al [91] reported that the susceptibility of various origins of biomass varies significantly.

The existing study trend focuses on the performance of WCO in asphalt blends [28]. The utilization of WCO in pavement enhances the performance of bitumen binder at minor temperatures, but this worsens with the upsurge in temperature [92]. In terms of the worldwide production of WCO, the US is the top producer, covering 55% or 10x10^6 tonnes of annual global production [93]. The Republic of Ireland is the lowest producer at 1% of annual global production or 153x10^3 tonnes [94]. According to a study by Azahar et al [82], Malaysia is responsible for only three percent of the annual global production of WCO due to the low conserving cost and surplus of palm oil farms in the country. Some scholars reported that the global production of WCO is virtually 15x10^6 tonnes per year [95][96][97]. However, only a small proportion has been properly collected and reused in the asphalt industry [98]. Figure 5 shows the global production of WCO per annum in some nations.

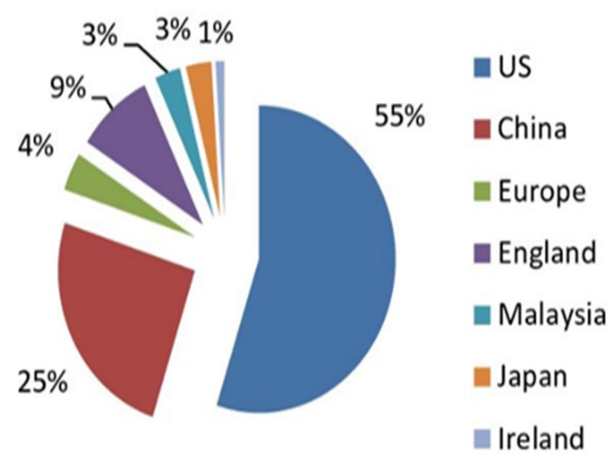
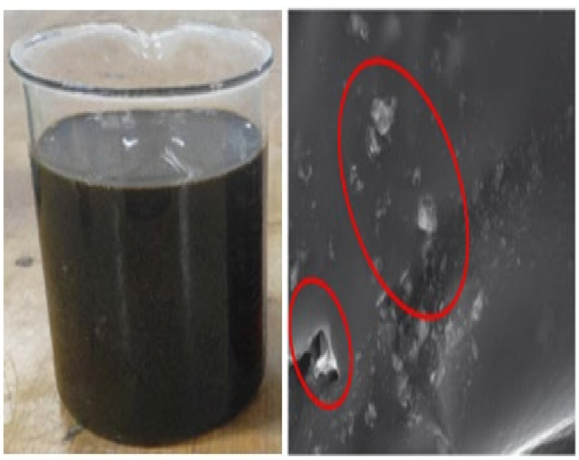


Figure 5 WCO global production per annum [97]

2.1.3 Waste Engine Oil (WEO)

Waste engine oil (WEO) is one of the various types of bio-oil wastes commonly used in sustainable pavement [83]. Also, WEOs are waste products of petrol, such as waste oils from vehicles, and they possess almost similar essential properties as bitumen [88]. WEOs have been produced in vast amounts in recent years as a result of the enhancement of humanity's existing standards and the improvement of vehicles [88].

As a mutual practice, vehicle workshops gather WEO remains from various automobiles, which generally contain pollutants from the wear of the vehicle engine, heating system, and oxidation of greasing oil during the operation of the engine [84]. WEO molecular structure has the same fundamental features as bitumen, demonstrating their potential for application in pavement construction to alleviate the toughening impact of recovered highway materials [88]. Therefore, small volumes of WEO if well mixed with reclaimed asphalt pavement might become useful in reducing the stiffness and toughening of aging bitumen [83]. Figure 6 shows the neat and rejuvenated WEO.



(a). (b).

Figure 6 (a) Neat WEO [88]; (b) WEO-modified binder [83]

As a result of high demand from the affordable and ecosystem to appropriately manage waste materials, the attention in reprocessing WEO has augmented [99]. The addition of WEO improved the minor temperature cracking resistance [99]. Shoukat and Yoo [100] indicated that WEO enhances the thermal cracking resistance of asphalt. Al-Saffar, et al. [101] discovered that WEO reduced the rutting behavior; this is due to the reduced adhesive and cohesive bond of the aggregate–bitumen, particularly at advanced temperatures. The research was made to evaluate the possibility of WEO as a modifier and recommended that this material be utilized to reestablish the fundamental properties of aged bitumen; however, it was also noticed that this material (WEO) had an undesirable influence on the aggregate–bitumen bond, indicating the utilization of antistripping agents [102].

Another study by Su et al [15] discovered that WEO has a negative influence on binder properties, such as reduced aggregate adhesive property, which assisted in raveling and stripping. Jia, et al. [103] also suggested against applying WEO on bitumen binder due to the damaging influence on the fatigue features of the bitumen binder. A study by Jahanbakhsh, et al. [104] discovered that the moisture vulnerability of reclaimed asphalt pavement (RAP) blends enhanced after increasing WEO into mixed binders with RAP (60%). Despite the additional paybacks offered by WEO transformation processes, they might have a damaging influence on the moisture damage resistance and rutting of asphalt concrete due to the content of wet aggregates and the absence of chemical and electrical propensity between the aging bitumen and aggregate surface due to the minor production temperatures [99].

Al-Saffar [101] studied the evaluation of the rheological and chemical properties of four types of asphalt binders with WEO and maltene (MLT) rejuvenators. The outcome of Fourier transform infrared spectra of the four types of asphalt binders is shown in Figure 7.

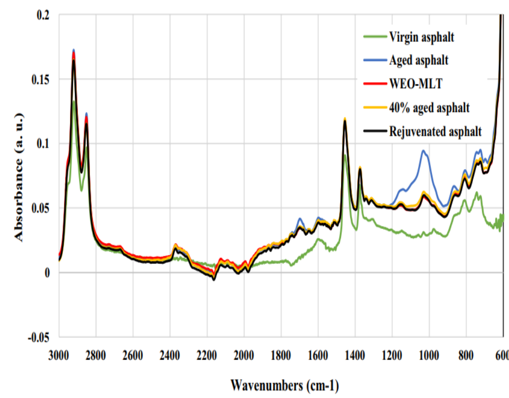


Figure 7 Fourier transform infrared analysis of asphalt binders [101]

According to the results of a study by Yel-Shorbagy [83], the addition of WEO to aging bitumen, the creep stiffness, and the degree of revived bitumen have satisfied the super pave standard specification limits, which proves that WEO enhanced the minor temperature thermal cracking of aging bitumen with a grade of PG 64-28. Different properties of WEO depend on the burning process, production and compaction temperatures, and sources of pollutants such as corrosion, dust, moisture, dilutants, cleansers, and engine wear metallic elements [83]. Table 2 provides the physical properties of WEO.

Table 2 Physical properties of WEO [88]

S/N	Property	Unit	WEO
1	Density	g/cm^3	0.89
2	Flash point	^0C	198
3	Viscosity @ 40^0C	cP	102

2.1.4 Sawdust Ash (SDA)

Sawdust (SD) is a neutral carbon waste generated from the processing of timber into various sizes and shapes, which are generally used in different applications, for example, renewable energy. If SD is used properly in pavement construction, it will reduce the global environmental issues affecting different countries, particularly underdeveloped and developing countries. This material is also considered a carbon-based waste product generated from timber milling machines in various sizes and shapes. Therefore, sawdust ash (SDA) is a type of pozzolana material generated by burning and is usually used as a source of domestic energy [53][54]. Similarly, the processing of SDA is a day-to-day activity that produces knolls of sawdust at the end of every day. Therefore, this establishes the transformation of waste into wealth and pollution into solution strategies [107]. There are many SDs in tropical nations, which can be used as a partial replacement for cement or as a filler in concrete in the form of ash [54][107][108]. Figure 8 shows the sawdust and its ash.

Figure 8 Sawdust and its ash

2.1.5 Rice Husk Ash (RHA)

Rice husk ash (RHA) is a neutral carbon waste produced globally per annum in large quantities. About $500x10^6$ tonnes of rice paddy are produced globally per annum. RHA if deposited in a landfill can develop an ecological issue, resulting in water and air contamination [109]. Almost 78% of the mass of paddy pulverized is produced as rice, bran, and broken grains, and thus, the outstanding mass of 22% of the paddy is produced as husk [109][110]. The husk is reused as fuel to produce steam [109][110]. The husk contains almost 75% carbon-based unstable materials and the remaining mass of 25% is inorganic materials [109][110]. During the burning process, 25% of the mass of this husk is converted into ash [109][110].

However, due to its high silica content, RHA is used as a partial replacement in asphalt concrete [110]. It is generally composed of aluminum oxide (Al_2O_3), silicon oxide (SiO_2), and iron oxide (Fe_2O_3), with trace quantities of magnesium oxide (MgO) and calcium oxide (CaO) [109][110]. The chemical composition of RHA is determined by the burning temperature and the period the rice husk is burnt [109][110]. The pozzolanic property of RHA is good due to its high dose of SiO_2, Al_2O_3, and Fe_2O_3 [109]. Figure 9 shows the rice husk and its ash.

Figure 9 Rice husk and its ash

2.1.6 Groundnut Shell Ash (GSA)

Groundnut shell (GS) is a carbon-neutral waste extracted from groundnut seeds and a significant amount of GS is discarded in landfills [7]. GS is an agricultural by-product produced from groundnut crushing under natural conditions [60]. Equally, a repeated process of groundnut occurs in a backlog of GSs that are not useful and are therefore either discarded, buried, or burnt [111]. However, the combustion of GSs for disposal or power generation results in the production of ash, and the disposal of this by-product into the environment could lead to an ecological issue [59][60].

However, groundnut shell ash (GSA) is generated from the combustion of GS at a temperature ranging from 550 ^{0}C to 600 ^{0}C [7][59][60]**.** Some published articles have focused on the utilization of GSA as a partial replacement, stabilization, or performance material in pavement construction [7][111][62]. This material can also be used in pavement construction to reduce material and construction costs, thereby increasing compressive strength, stabilization, and reinforcement of other compounds [7][62][63]. GSA chemical composition is obtained from x-ray fluorescence spectrometry investigation, and it was detected that the key oxides in GSA were Al_2O_3 and SiO_2 [116]. Figure 10 shows the groundnut shell and its ash.

Figure 10 Groundnut shell and its ash

2.1.7 Sugarcane Bagasse Ash (SCBA)

Sugarcane is one of the most extensively produced crops in the world, with more than 110 countries as manufacturers [20]. Bagasse is a neutral carbon waste of sugarcane refining. When this material is crushed at a particular temperature, it produces "ash" known as sugarcane bagasse ash (SCBA) [20]. The fiber by-product after the crushing and mining process from sugarcane is used to produce juices. In the construction industry, SCBA is used for the stabilization of reclaimed asphalt pavement (RAP) and replacement of cement as filler in hot mix asphalt (HMA) or warm mix asphalt (WMA) concrete [20][65][117]. Based on previously published studies, SCBA appears to be a more sustainable material than other neutral carbons, particularly for HMA concrete. Additionally, this material is inexpensive and widely accessible in Malaysia.

Murana and Sani [57] studied the partial replacement of cement-incorporated SCBA in HMA. The results of the study indicated that SCBA has a mass of combined Al_2O_3, SiO_2, and Fe_2O_3 of 50% by mass of fraction. This indicated that SCBA fits class "C" (Al_2O_3 + SiO_2 + Fe2O3 = 53.4%). Therefore, SCBA can be used as a partial replacement for cement in HMA as a mineral filler. However, SCBA chemical composition is obtained from x-ray fluorescence spectrometry investigation, and it was detected that the key oxides in SCBA were SiO_2 and CaO [61][65]. Figure 11 shows the sugarcane bagasse and its ash.

Figure 11 Sugarcane bagasse and its ash

2.1.8 Coconut Shell Ash (CSA)

Coconut shell (CS) is one of the neutral carbon wastes that should be disposed of appropriately in the environment. CS accounts for over 60% of domestic waste, posing grave disposal anxiety to the environment and its inhabitants [119]. This material can be used in different applications through reprocessing as potential replacement material in the construction industry [120]. It has been observed that out of 100 kg of coconut, around 15 kg of CS is generated for sustainable use [119]–[121]. Coconut is grown in more than 90 countries on 14.231×10^6 hectares, with a total production of 11.04×10^6 metric tonnes of coconut equivalent [121][119]. Indonesia, the Philippines, and India are the top producers of coconut with a production rate of 25.63%, 23.91%, and 19.20% respectively [122]. However, CS is used in various applications, for example, the production of cement-based materials, bioenergy production, petroleum technology, the microelectronic industry, nanomaterials, and complex materials [123][124].

However, the chemical composition of coconut shell ash (CSA) has a SiO_2 having the highest chemical composition of 45.05% (see Table 3) [119]. Alternatively, CSA is durable, because it has a large proportion of Al_2O_3, SiO_2, and Fe_2O_3, all of which are identified to be among the major sustainable chemical compositions [119]. Additionally, CSA comprises other oxides such as CaO, MgO, TiO_2, K_2O, ZnO, etc. [119]. Figure 12 shows the coconut shell and its ash.

Figure 12 Coconut shell and its ash

2.1.9 Dates Seed Ash (DSA)

Dates seeds (DS) are neutral carbon wastes generated from dates after removing their cover as a fruit. DS is generally rectangular, brown in color, and firm. Date seeds are commonly used in decaffeinated coffee and foods for creatures [125][73]. This waste is also used as a raw product for triggered carbon and the performance of HMA in the chemical and asphalt industries respectively (Figure 13) [125]. DS has recently found a state-of-the-art utilization in the asphalt industry as a replacement agent in asphalt mixtures [125][126]. The effects of the activated DS on the performance of HMA and the behavior of asphalt mixtures with DSA have been made by some published studies [125][127]. Therefore, DSA chemical composition is obtained from x-ray fluorescence spectrometry investigation, and it was noticed that the key oxide in DSA was SiO_2. The triggered structure of SiO_2 can enhance binder absorption and stability of chemicals [1][75]. The summary of various chemical compositions of NC&BoWs is presented in Table 3.

Figure 13 Dates seed and its ash

Table 3 A summary of various chemical compositions of NC&BoWs

Reference	NC&BoWs	Chemical composition					
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Others
[16]	SDA	26.17	4.53	1.82	44.11	5.34	25.33
[109]	RHA	90.18	0.51	0.17	2.64	0.70	5.80
[116]	GSA	54.03	39.81	4.34	1.70	0.004	0.12
[118]	SCBA	62.43	4.38	6.98	11.80	2.51	11.90
[119]	CSA	45.05	15.60	12.40	0.57	16.20	10.18
[126]	DSA	58.60	4.90	7.90	4.80	3.90	19.90
[129]	CBA	65.20	32.00	22.10	24.00	18.20	-
[130]	WCO	100.00	82.23	97.04	80.90	80.00	-

2.2 Effects of Other NC&BoWs

The quick population growth, technical progressions in the industry, and the extensive use of state-of-the-art goods and services have all promoted a quick upsurge in the amount and poisonousness of current waste produced in current decades [131]. A review of the thermal properties of the municipal solid waste mechanisms shows that heat produced during the decay of waste mechanisms would mainly be moved to leachate because of the establishment of water and vaporous mechanisms and their large specific temperatures [132]. The use of municipal waste as a partial substitute for raw products in the construction industry saves valuable landfill space and decreases the necessity for the mining of traditional raw products [131]. Steel slag (SS) is made as a by-product in substantial quantities during the process of making steel by using an inundated electric arc furnace [131][133]. An SS has enticed the attention of some scholars as a possible green and justifiable construction material due to its exceptional chemical, physical, and mechanical properties [131][133].

The mixture of by-products in asphalt concrete challenges three ecological problems, which are global warming, air pollution, and solid waste management [99]. Cheraghian et al [134], revealed that almost 39 percent of asphalt mixtures were made as WMA mixtures, which develops compaction efforts, air void reduction, and reductions of power demands at lesser temperatures. WMA production is usually expensive and untenable [75]. Some published studies associated with industrial by-products in asphalt roadways discovered that WMA improves pavement behavior while reducing construction expenses [135][136].

A study made by Ijeoma [137] on the mechanical performance of lateritic soil improved with bone ash (5%, 10%, 15%, and 20%) and hydrated lime (3%, 9%, and 15%) for utilizations of sustainable building. The outcomes of the investigation reported that the optimum content of hydrated lime (9%) and bone ash (5%) improved the compressive strength of lateritic soil significantly, after 28 days of curing.

Sustainable asphalt pavements promise a wide-ranging reduction in the consumption of natural resources, and power consumption, and a reduction in toxic vapors during pavement construction, thereby creating an impact on the ecosystem and financial industry [138][139]. Thus, the use of WMA is a beneficial mechanism for incorporating waste products (NC&BoWs) in asphalt pavement establishing more usually, a surface that is in potential with the intention of sustainable asphalt construction [21]. However, the asphalt pavement is affected by several distresses as a result of some drivers as depicted in Figure 14.

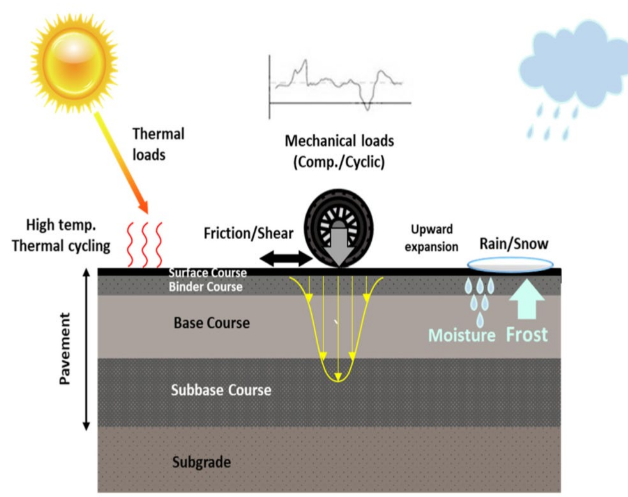


Figure 14 Common drivers for asphalt pavement distress [140]

Contradicting results have been specified concerning the behaviours of WMA mixtures, which can be attributed to the numerous kinds of WMA mixtures; quantity of warm mix additive; category and quantity of other modifying agents in WMA; and trial methods used for the assessment of WMA mixtures and modified binders [141]. Other NC&BoWs have been used in numerous countries to produce asphalt concrete (see Figure 14) [142][143][52].

The possibility of using wooden charcoal as a filler material in stone mastic asphalt (SMA) was studied by Shankaracharya et al [144] to enhance the permanence and quality of the pavements. Three various fillers comprising FA, cement, and stone dust were related to wooden charcoal using the Marshall stability and flow test to determine the appropriateness of utilizing wooden charcoal as a filler material in SMA. The outcomes of the study showed that wooden charcoal can be used as a filler material as it satisfies all of the specification limits of the test [144].

Dimter et al [145] studied the laboratory assessment of the various properties of asphalt mixtures with wood ash filler (WAF). The results of the study have discovered that WAF (50%) enhanced asphalt resistance to the appearance of tensile strength, and plastic deformations, and produced good water resistance.

A study by Patil et al [124] studied the suitability of using coconut shell charcoal (CSC) as a structural filler material in SMA for three various fillers, comprising stone dust, FA, and Portland cement. The results of the study have discovered that CSC can be used as a filler material in SMA since it satisfies all of the specification limits of the test.

Muniandy et al [146] studied the effect of mineral filler particle size and category on rheological and behaviour features of SMA asphalt filler mastics. A binder and four various fillers including ceramic waste (CW), limestone (LS), steel slag (SS), and coal fly ash (CFA) were selected to test the rheological and performance properties of asphalt filler mastics. The results of the study have revealed that using a fine to coarse particle size filler enhances the pavement rutting while using a coarse to fine particle size filler enhances the resistance to fatigue cracking of the tried asphalt filler mastics at a specific ratio. The results have also revealed that the fine particle size of asphalt mastics had a lesser viscosity, larger penetration, and lesser softening point compared to a coarse particle size of asphalt mastics. Additionally, the ceramic filler was discovered to be more effective compared to control mastic in making asphalt mastics that are more flexible and less susceptible to rutting and fatigue cracking. Figure 15 shows other neutral carbon materials (NCMs) for sustainable pavement construction.

Figure 15 Other NCMs [147][148]

3.0 EFFECTS OF OTHER NCMs AND WMA TECHNOLOGIES

The degree to which the construction sector discovers and consumes non-recyclable natural aggregates and additional municipal products for instance bitumen, cement, and lime in the course of construction and restoration of pavements has over time proved to be ecologically humiliating and non-viable [149]. This, together with the problems of large solid waste production and insufficient disposal, has led to a sequence of investigations by many researchers to determine approaches to incorporate solid wastes as substitute materials in pavement construction and management [149][132].

On the other hand, the cumulative growth of the oil sector has resulted in large quantities of several waste products, which require appropriate discarding and valorization [150]. The difficulty, rate of slowness, and high cost of numerous remediation approaches for wastes from the oil sector and the possibility of using these wastes in construction industries have enticed large attention from researchers globally [150].

Rejuvenation of bitumen binders with pure polymers is a combined application in the pavement construction industry, as it is an actual way to improve pavement behavior [34]. In current years, polymeric waste has arisen as a state-of-the-art method to rejuvenate bitumen binders and asphalt blends with the assurance of enhancing pavement behavior while decreasing construction expenses and the quantity of polymeric waste in the ecosystem [34].

Issa [151] studied the influence of adding crushed glass (CG) to asphalt mixtures. Specific gravity and Marshall properties of the asphalt mixtures were evaluated in a laboratory setup. CG (5%, 10%, and 15%) was added to the asphalt mixture by mass of aggregate at varying bitumen contents to produce specimens. The results of the study have shown that the potentials of the CG-asphalt mixture are enhanced than conventional asphalt mixture. Hence, the CG used in the asphalt mix was discovered to be positive.

Madupe et al [152] studied the performance assessment of HMA concrete integrated cow bone ash as a partial substitute for filler. The traditional filler (quarry dust) was partially substituted with cow bone ash at 2.5%, 5.0%, 7.5%, 10.0%, 20.0%, 30.0%, 40.0%, and 50.0% respectively, in the whole mix. The results of the study discovered that the stability and flow of the asphalt mixture with cow bone ash were more than that of the asphalt mixture with traditional filler (quarry dust). Also, the volumetric and physical properties of the mixture enhanced as cow bone ash were noticed to be finer compared to quarry dust, indicating a reduction in the voids present in the total mix and hardened the binder film on the aggregate elements. The results of the study have also indicated that the quarry dust can be substituted partly with cow bone ash up to 50 percent.

Behnood and Ameri [153] conducted an experimental investigation of SMA mixtures with steel slag (SS). The results of the study have shown that the use of SS as a partial replacement of coarse aggregates can improve Marshall properties, tensile strength, resilient modulus, resistance to perpetual deformation, and resistance to moisture damage of SMA mixtures. The state-of-the-art application of non-clay additives has significantly improved behaviors or processing situations [154]. The quick upsurge in SS production worldwide highlights the imperative necessity to protect the disposal or application methods [155]. Regarding traditional landfill disposal, global scholars have successfully reprocessed SS in the construction, agricultural, and chemical industries [133][155]. With the huge percentages of alkaline silicate mineral content, SS can also be utilized as an appropriate material for carbon capture to lessen universal warming [155].

A study by Jegatheesan et al [14] studied the mechanical properties of modified HMA with polyethylene terephthalate fibers (PTFs) to replace binder additives and carbonized wood particles (CWPs) to replace fine aggregates. The results of the study have shown that different mechanical properties of modified HMA were assessed in a laboratory setup, indicating better-quality improvement of modified HMA concrete. Maidin et al [157] reported that manufacturing additive offers a fast and active restoration remedy when product breakdowns and precise substitution components are unobtainable or restricted.

Regarding the WMA technologies, Zhao et al [158] discovered that WMA mixtures have a lesser amount of rutting resistance compared to HMA mixtures because of the less aging limitation used in their making. Behnood [141] stated that the WMA production technique reduces the production and compaction temperatures through the regulation of the various characteristics of the WMA mixes and binders. Nevertheless, the rejuvenation in the binder characteristics in a WMA mix, such as viscosity, can be either provisional or perpetual depending on the period and temperature [133][159][160].

The WMA technologies primarily decrease the viscosity of the binders for the production and compaction of asphalt mixtures [161][162]. These technologies can also have different effects on the physical and durability characteristics of WMA mixes and the rheological characteristics of binders [141][163]. Generally, WMA technologies can be classified into three types: (i) organic technologies such as sasobit, licomont 100, asphaltan B, etc., (ii) chemical technologies such as evotherm, zycotherm, rediset, iterlow, etc., and (iii) foaming technologies such as water-bearing process and water-based process [161][162]. Among these various types of WMA technologies, chemical technologies usually do not have a significant effect on binders' rheological features [161][162].

Sustainable pavement substructure is critical for recent monetary and ecological concerns [164]. In the past 10 years, the pavement substructure powerfully supported the quick development of the worldwide community economy [164]. State-of-the-art theories, state-of-the-art approaches, state-of-the-art skills, and state-of-the-art materials correlated to roadway engineering are developing [164]. The construction of an environmentally friendly roadway can be realized thanks to various WMA technologies guaranteeing porous, self-luminous, noise-reduction, and exhaust-disintegrating characteristics in addition to supporting lesser heat engrossing and boosted anti/de-icing qualities [165].

4.0 METHODOLOGY

This section provides a summary of the different materials and methods from the previously published articles to achieve the study's purpose. The study flowchart is depicted in Figure 16.

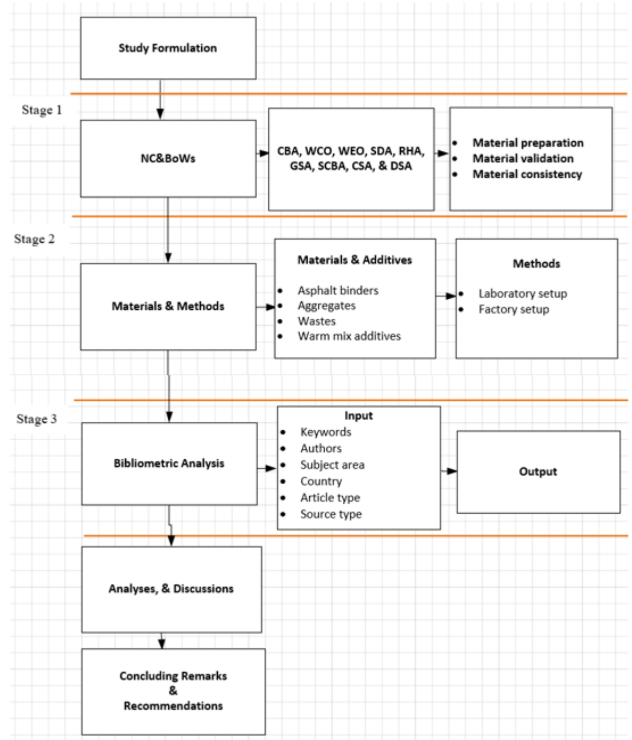


Figure 16 Study flowchart

4.1 Materials

Materials such as bitumen, aggregates, and neutral carbon and bio-oil wastes (NC&BoWs) such as CBA, WCO, WEO, SDA, RHA, GSA, SCBA, CSA, and DSA can be incorporated directly into WMA to produce a homogeneous modified specimen. The bitumen and NC&BoWs contents to be used depend on the standard specification of the test method. Based on the previously published articles, the bitumen and NC&BoWs contents were measured by the weight of aggregate and bitumen respectively. The production and compaction temperatures range from 100 ^{0}C to 150 ^{0}C for WMA. Nevertheless, various properties of modified bitumen and modified WMA concrete can be determined either in the laboratory or factory setups.

4.2 Methods

Different tests on WMA mixtures are usually carried out either in the laboratory or factory setups. Based on the prior studies, almost all the tests were made to the standard requirements of JKR 2008. Bitumen and aggregates were heated at a temperature of 145 ^{0}C (warm mixture) for 45 minutes before the laboratory analysis. The specimens were prepared by blending the modified bitumen with the aggregates by the standard specifications for asphalt work. Marshall mixes design proportions for NC&BoWs (0% to 10%) by weight of bitumen, bitumen (5.0% to 7.0% for AC10, and 4.0% to 6.0% for AC14) by weight of aggregate was recommended by the previous researchers.

5.0 BIBLIOMETRIC ANALYSIS

Figure 17 shows the analysis of bibliographic coupling by authors from 2012 to 2023. It was clear that the authors had a good relationship with each other. Also, between 2012 and 2023, Scopus published 26 articles. Based on the findings displayed in Figure 18, these published Scopus articles indicate that there is a mutual collaboration across different organizations. Notably, different authors have written distinct Scopus articles. Figure 19 shows the strong relationships that were discovered between the various study's keywords. As Figure 20 demonstrates, there is a strong correlation between co-citation and cited authors.

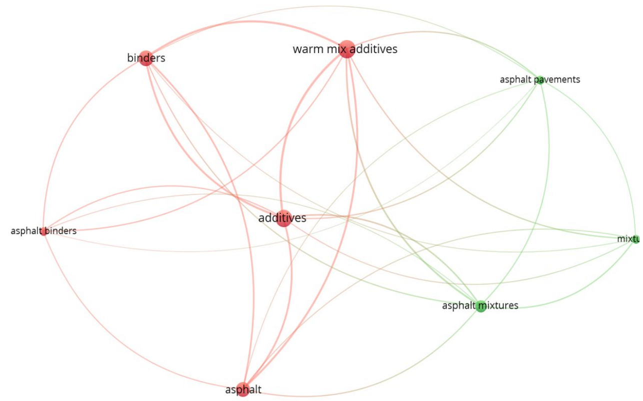


Figure 19 Keyword relationships between 2012 and 2023

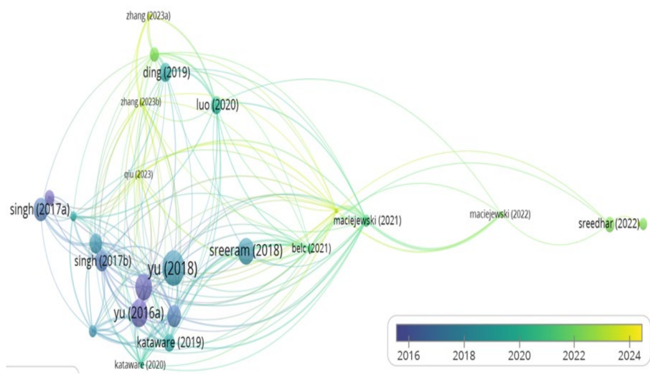


Figure 17 Relationship between authors from 2012 to 2023

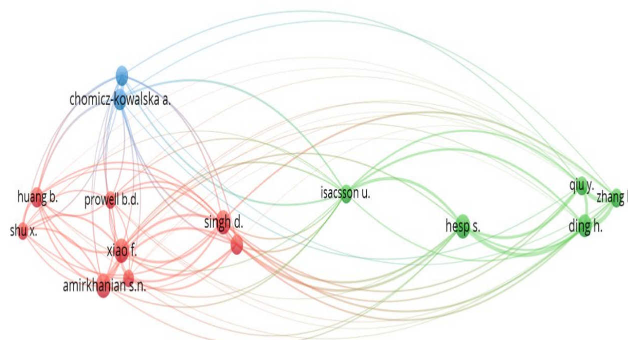


Figure 20 Correlation between co-citation and cited authors from 2012 to 2023

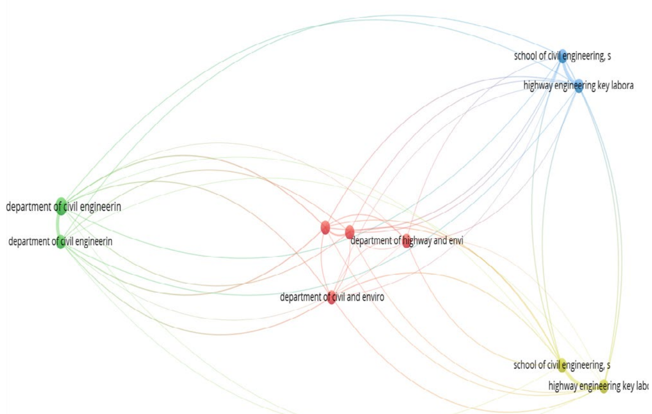


Figure 18 Relationship between organizations from 2012 to 2023

Furthermore, two articles were published by Scopus in 2012, and no single article was published until 2016, as Figure 21 illustrates. Up to 2018, Scopus publication continued, however, Scopus's publishing rate decreased until 2020. Up to 2021, two articles were published consistently. After that, Scopus continued to publish continuously until 2023. Significantly, Scopus published a maximum of five articles in 2023. Figure 22 shows the annual Scopus publications from 2012 to 2023 sorted by source. Scopus published a maximum of five articles in 2023. However, one article was published by Scopus in 2012.

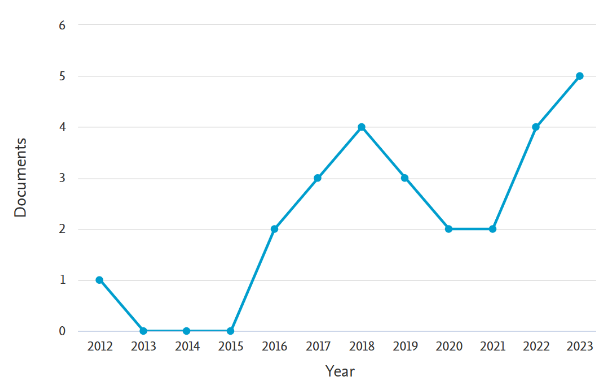


Figure 21 Scopus articles published between 2012 and 2023

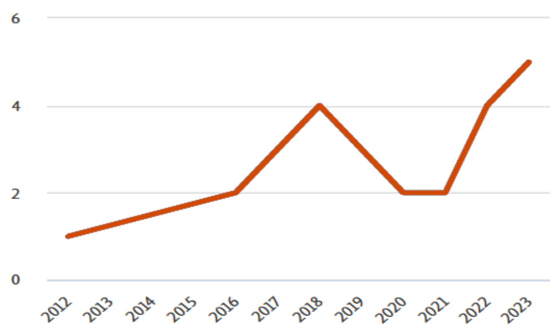


Figure 22 Scopus articles published annually by source between 2012 and 2023

Based on the current findings, ten authors published various articles between 2012 and 2023. As Figure 23 shows, Singh, D. published the highest number of Scopus articles, followed by Qiu, Y. Three Scopus articles were published by Coleri, E, Habal, A., Maciejewski, K, and Yu, H., respectively. Figure 24 shows that India published the highest number of Scopus articles with nine, and China came in second with eight. Romania and South Korea published one Scopus article, respectively.

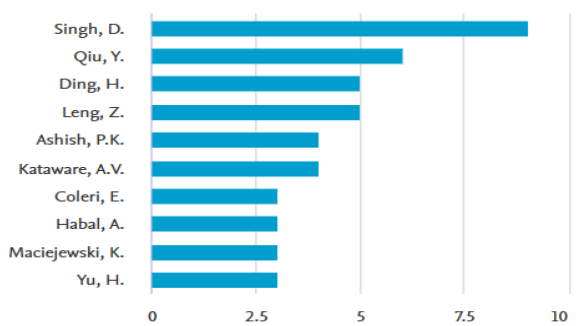


Figure 23 Scopus articles published by authors between 2012 and 2023

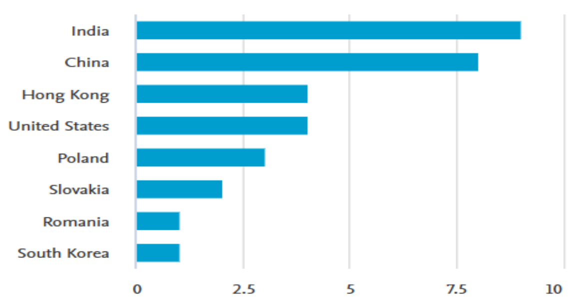


Figure 24 Scopus articles published by Countries between 2012 and 2023

Figure 25 shows that 100.0% of full-length articles were published by Scopus between 2012 and 2023. Based on the review article, it seems that not a single review article was accepted and published by Scopus. Figure 26 shows the Scopus articles published by three subject areas between 2012 and 2023. The fields of engineering, materials sciences, and physics and astronomy published 50.0%, 43.5%, and 6.5% of the Scopus articles, respectively. Table 4 provides a summary of the Scopus articles published from 2012 to 2023.

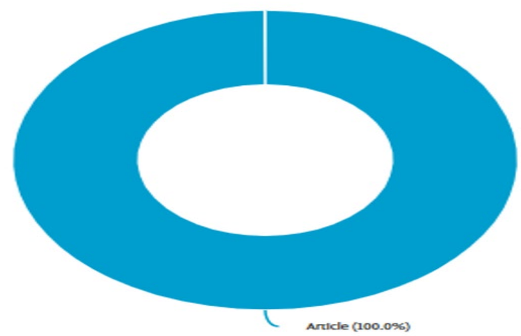


Figure 25 Scopus articles published by type between 2012 and 2023

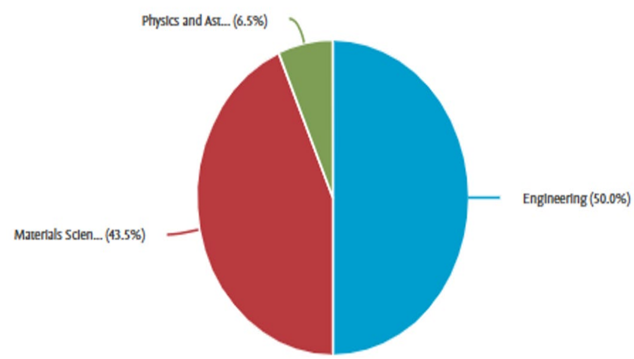


Figure 26 Scopus articles published by subject area from 2012 to 2023

To recap, NC&BoWs have promising potential for sustainable WMA concrete, indicating the establishment of a friendly environment for the inhabitants. Table 5 summarizes the review findings from the previously published articles on asphalt concrete with some NC&BoWs.

Table 4 A summary of the Scopus articles published from 2012 to 2023

S/N	Author	Year	Journal title	Volume	Cited by	Publisher	ISSN	Source
1	Sreedhar S.; Coleri E.	2022	International Journal of Pavement Engineering	23	22	Taylor and Francis Ltd.	10298436	Scopus
2	Belc et al.	2021	Materials	14	8	MDPI AG	19961944	Scopus
3	Yu et al.	2016	Construction and Building Materials	111	66	Elsevier Ltd	9500618	Scopus
4	Yu et al.	2018	Construction and Building Materials	175	111	Elsevier Ltd	9500618	Scopus
5	Singh D.; Ashish P.K.; Chitragar S.F.	2018	Construction and Building Materials	158	35	Elsevier Ltd	9500618	Scopus
6	Al-Qadi et al.	2012	Journal of Materials in Civil Engineering	24	23	American Society of Civil Engineers (ASCE)	8991561	Scopus
7	Zhang et al.	2023	Construction and Building Materials	368	2	Elsevier Ltd	9500618	Scopus
8	Maciejewski et al.	2022	Construction and Building Materials	341	4	Elsevier Ltd	9500618	Scopus
9	Kataware A.V.; Singh D.	2017	Construction and Building Materials	146	45	Elsevier Ltd	9500618	Scopus
10	Ding H.; Qiu Y.; Rahman A.	2019	Journal of Materials in Civil Engineering	31	32	American Society of Civil Engineers (ASCE)	8991561	Scopus
11	Zhang H.; Qiu Y.	2023	Construction and Building Materials	389	0	Elsevier Ltd	9500618	Scopus
12	Qiu et al.	2023	International Journal of Pavement Engineering	24	0	Taylor and Francis Ltd.	10298436	Scopus
13	Yu H.; Leng Z.; Gao Z.	2016	Construction and Building Materials	125	64	Elsevier Ltd	9500618	Scopus
14	Sreeram et al.	2018	Construction and Building Materials	179	63	Elsevier Ltd	9500618	Scopus
15	Kataware A.V.; Singh D.	2020	Road Materials and Pavement Design	21	4	Taylor and Francis Ltd.	14680629	Scopus
16	Singh D.; Chitragar S.F.; Ashish P.K.	2017	Construction and Building Materials	157	47	Elsevier Ltd	9500618	Scopus
17	Singh et al.	2017	Journal of Materials in Civil Engineering	29	42	American Society of Civil Engineers (ASCE)	8991561	Scopus
18	Habal A.; Singh D.	2022	Road Materials and Pavement Design	23	15	Taylor and Francis Ltd.	14680629	Scopus
19	Kataware A.V.; Singh D.	2019	International Journal of Pavement Engineering	20	30	Taylor and Francis Ltd.	10298436	Scopus
20	Kataware A.V.; Singh D.	2018	Construction and Building Materials	184	13	Elsevier Ltd	9500618	Scopus
21	Singh et al.	2019	Journal of Materials in Civil Engineering	31	10	American Society of Civil Engineers (ASCE)	8991561	Scopus
22	Chomicz-Kowalska et al.	2023	Materials	16	0	Multidisciplinary Digital Publishing Institute (MDPI)	19961944	Scopus
23	Kumar V.; Coleri E.	2023	Construction and Building Materials	394	1	Elsevier Ltd	9500618	Scopus
24	Luo et al.	2020	Construction and Building Materials	231	30	Elsevier Ltd	9500618	Scopus
25	Qiu Y.; Ding H.; Su T.	2022	International Journal of Pavement Engineering	23	19	Taylor and Francis Ltd.	10298436	Scopus
26	Maciejewski et al.	2021	Materials	14	15	MDPI	19961944	Scopus

Table 5 A summary of the review findings from the previously published articles

Reference	Material used	Review findings
[83][88]	WCO & WEO	For the penetration and softening point experimental results, the optimum contents were obtained to vary from 3.5% to 4.0% for the WCO, and from 5.5% to 6.0% for the WEO. On the other hand, the outcomes of the assessments revealed that the mixing of WEO and WCO with virgin bitumen enhances the workability of aging bitumen.
[99]	WEO	The modification of aged bitumen with WEO (12%) enhances the moisture vulnerability of the asphalt mixtures.
[137]	Bone ash and hydrated lime	Bone ash (5%) and hydrated lime (9%) improved the compressive strength of lateritic soil significantly, after 28 days of curing.
[161]	Dust and benzene soluble fraction	Dust and benzene soluble fractions produced behind the paver were reduced by 30% and 63% respectively. Similarly, dust and benzene soluble fractions produced at the site of the paver were reduced by 85% and 72% respectively.
[166]	SDA	Treating black cotton soil with SDA (16%) in a suitable ecology and integrated with lime (4%) develops its strength.
[167]	RHA	RHA can be utilized as a cement preservative to enhance the flexural and compressive strengths of cement mortar samples. It was proved that the RHA alternative of 10% (by mass of bitumen) has the greatest advancement impact on the strengths of cement.
[168]	MK & GSA	The increase of metakaolin (MK) and GSA individually and collectively as a partial alternative of FA in the SCGC blends causes a decrease in the workability, whereas the toughened characteristics of SCGC are considerably improved with MK and GSA individually and collectively up to ten percent by the mass of FA.
[169]	SCBA & CBCs	The increase of SCBA in cement-based composites (CBCs) as cement alternative was reported to be optimistic about sustainability features and behavior of composites.
[170]	DPP & PU	The date palm particle (DPP)-polyurethane (PU) is a good parameter for the advancement of effective, economical, and safe insulating products.
[171]	Zycosoil	Zycosoil (1%, 2.5%, and 4%) by mass of bitumen improves the rheological characteristics of bitumen. The performance mixture was influenced by a high dose of CR, and this influence was enhanced by the incorporation of zycosoil.
[172]	CBA	The production of CBA is expected to improve at an average rate of 0.1% per annum over the next 20 years.
[173]	WCO	The optimum creep stiffness, with an enhancement of almost 25% based on the control mixture, was achieved with a 5% preserved WCO mixture to resist the permanent deformation of pavement.
[174]	GSA	GSA chemical properties as related to cement, the volume of potassium oxide was bigger in GSA and calcium oxide was not more than what is gotten in cement.
[175]	CSA & CSP	CSA (10%) and CSP (5%) in reinforced concrete beams enhanced ductility by 8.8% without considerably decreasing maximum failure load (P_{max})

6.0 CONCLUDING REMARKS AND RECOMMENDATIONS

The purpose of this study was to provide a comprehensive review of the use of neutral carbon and bio-oil wastes (NC&BoWs) on WMA concrete from an eco-friendly perspective. The following conclusions can be drawn from the study:

i. By converting wastes into wealth and pollution into solutions, the use of NC&BoWs such as CBA, WCO, WEO, SDA, RHA, GSA, SCBA, CSA, and DSA can save a significant amount of waste products and open the door to acceptable improvement.

ii. It was discovered that the researched NC&BoWs improved the various qualities of regenerated asphalt binders.

iii. Several nations have produced sustainable asphalt concrete using additional NC&BoWs including coconut shell charcoal, stone dust, quarry dust, cow bone ash, hardwood charcoal, limestone, steel slag, coal fly ash, broken glass, carbonized wood particles, etc.

iv. Using WMA to incorporate NC&BoWs into asphalt concrete is a helpful method that typically creates a surface with the potential to build sustainable pavements.

v. Several studies have found that when WMA mixtures are produced with less aging limitation than HMA mixtures, they are less resistant to rutting.

vi. Published articles have reported that the WMA production technology reduces the production and compaction temperatures through regulation of the various characteristics of the WMA mixes and asphalt binders.

vii. The WMA technologies reduce the viscosity of the asphalt binders mainly to produce and compact asphalt concrete.

viii. WMA technologies can be divided into three categories: chemical, organic, and foaming technologies, respectively. Therefore, the rheological properties of asphalt binders are typically not significantly impacted by chemical processes.

ix. Various researchers have employed various materials and methods to assess the characteristics of asphalt binders included in NC&BoWs in both industrial and laboratory settings.

x. A bibliometric analysis reveals that only 26 out of the 168 articles related to this study were published by Scopus between 2012 and 2023. Full-length articles accounted for 100.0% of Scopus publications, and it seems that not a single review article was accepted and published by Scopus. Based on the subject area, the fields of engineering, materials sciences, and physics and astronomy published 50.0%, 43.5%, and 6.5% of the Scopus articles, respectively.

Consequently, the findings suggested that further reviews are necessary to verify NC&BoWs' ongoing efficacy in WMA concrete.

Conflict of interest

There is no conflict of interest between the authors.

Acknowledgments

This study was supported by the Universiti Teknologi Malaysia, Johor Bahru (UTMJB) with a Vote No.: R.J130000.7351.4B703.

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