

## Publications Relating to Biochar as a Component of Asphalt

This brief bibliography was prepared by using Google Scholar with a simple 3-word search string: "pavement" "biochar" "asphalt". That generated 370 results. The first five pages of results are recorded in Section 1. (Just less than 50 results.)

Two comments:

- 1) A minor point of terminology: The word 'pavement' is used in the engineering sense (a road surface), not to be confused with the British colloquial sense which means a sidewalk.
- 2) Most of the results seem to be based on hot- or warm-mix asphalt. Much less is published about "cold mix". The number of results was as follows for the two search strings:

- "pavement" "biochar" "asphalt" "hot mix": 81 hits
- "pavement" "biochar" "asphalt" "cold mix": 8 hits

The eight results including "cold mix" are recorded in SECTION 2.

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### SECTION 1

Page 1

#### Laboratory investigation of **biochar**-modified **asphalt** mixture

[S Zhao, B Huang, X Shu, P Ye - Transportation Research ...](#), 2014 - journals.sagepub.com  
... With the emergence of nano- technology in the last decade or so, nanosized carbon fibers were used by highway engineers in **pavement** engineering (10, 11) ... However, performance of the **asphalt** mixtures with **biochar**-modified binder is still unknown and needs to be ...

*From the abstract:*

*On the basis of test results, the biochar evaluated in this study proved to be an effective modifier in reducing the temperature susceptibility of the binder and thus increased the rutting, moisture, and cracking resistance of hot-mix asphalt. In addition, biochar proved to be a better asphalt modifier than did carbon black and carbon fiber.*

#### Evaluation of bio-**asphalt** binders modified with **biochar**: a pyrolysis by-product of *Mesua ferrea* seed cover waste

[A Kumar, R Choudhary, R Narzari, R Katakati...](#) - Cogent ..., 2018 - Taylor & Francis  
... A large amount of carbonaceous **biochar** is generated as a by- product during the pyrolysis. However, no major effort has been made in the past decade to utilize the **biochar** in **pavement** applications, especially as a bio-modifier to **asphalt** binders ...

*From the abstract:*

*Physical and chemical characterizations of biochar were carried out using scanning electron microscopy, Fourier transform infrared spectroscopy and energy dispersive X-ray analysis. This was followed by rheological characterization of asphalt binders (from two sources) modified with various concentrations of biochar (0, 5, 10, 15, and 20% by weight of binder). Flow behaviour, permanent deformation, and fatigue characteristics of bio-asphalts were evaluated and compared with control binders (no biochar). Aging susceptibility of biochar modified binders was also evaluated and compared for biochar contents and binder sources. Permanent deformation behaviour evaluated through multiple stress creep and recovery (MSCR) test indicated that the use of biochar improved the rutting resistance of binders. Improved binder performance against the effects of aging and deformation with the use of biochar*

*makes it a promising asphalt modifier, especially for the warm tropical climatic conditions prevalent in India.*

### Influence of warm-mix **asphalt** technology and rejuvenator on performance of **asphalt** mixtures containing 50% reclaimed **asphalt pavement**

W Song, B Huang, X Shu - Journal of Cleaner Production, 2018 - Elsevier

... Influence of warm-mix **asphalt** technology and rejuvenator on performance of **asphalt** mixtures containing 50% reclaimed **asphalt pavement** ... The use of reclaimed **asphalt pavement** (RAP) in **pavement** construction has been becoming an extensive concern since the 1970s ...

*From the abstract:*

*(The word "biochar" only appears in references.)*

### Effects of **biochar** on the chemical changes and phase separation of bio-**asphalt** under different aging conditions

X Zhou, G Zhao, S Wu, S Tighe, D Pickel... - Journal of Cleaner ..., 2020 - Elsevier

... and aromatization structure (Lonappan et al., 2020). **Biochar** can improve **asphalt pavement** performance (Fu et al., 2015), and it is a renewable and environmentally friendly material. The addition of **biochar** also improve flow ...

*From the abstract:*

*Bio-asphalt replaced petroleum-asphalt for paving asphalt pavements, which is a technology with a wide range of application prospect. This work is aimed at improving the performance of aged bio-oil modified asphalt (bio-asphalt) for use in road pavement construction. Biochar and bio-oil are renewable resources and use in this research that are pyrolyzed from waste wood. The effects of different aging conditions on biochar-modified bio-asphalt and ordinary bio-asphalt were investigated in terms of their chemical functional groups, molecular formulas, radius distribution functions, rheological parameters, and phase separation.*

### Factors determining the potential of **biochar** as a carbon capturing and sequestering construction material: critical review

S Gupta, HW Kua - Journal of Materials in Civil Engineering, 2017 - ascelibrary.org

... Chemical stability is an important criterion for applying **biochar** with concrete in buildings and with **asphalt** for **pavement** construction, to ensure that no harmful products are formed from the reaction of **biochar** with other components in the concrete mix ...

*From the abstract:*

*In this review, attention was focused on evaluating biochar's capability for carbon adsorption, which depends on factors such as pyrolysis conditions (specifically, pyrolysis temperature, heating rate, and pressure) and activation methods (and without surface modification).*

### Laboratory evaluation of **pavement** performance using modified **asphalt** mixture with a new composite reinforcing material

Z Fu, W Shen, Y Huang, G Hang, X Li - International Journal of Pavement ..., 2017 - Elsevier

... Google Scholar. [3] Jeonga Kyu-Dong, Lee Soon-Jae, KW Kim Laboratory evaluation of flexible **pavement** materials containing ... 118-122. Google Scholar. [10] Sheng Zhao, Bao-shan Huang, Xiang Shu Laboratory investigation of **biochar**-modified **asphalt** mixture. Transp ...

*From the abstract:*

*(The word "biochar" only appears in references.)*

## Modeling of the Complex Modulus of **Asphalt** Mastic with **Biochar** Filler Based on the Homogenization and Random Aggregate Distribution Methods

Y Wu, P Cao, F Shi, K Liu, X Wang, [Z Leng](#)... - *Advances in Materials* ..., 2020 - hindawi.com

... To further explore the essence of **biochar** on strengthening **asphalt pavement**, modeling methods are highly required. Currently, the method to predict the complex modulus of **asphalt** materials can be divided into numerical methods and analytical methods ...

*From the abstract:*

*The disposal of agricultural straw has been a severe environmental concern in China and many other countries. In this study, the complex modulus of using biochar converted from straw as an alternative mineral filler in asphalt mastic was investigated through both laboratory tests and modeling. The experimental results indicated that the biochar can provide asphalt mastic higher stiffness than the conventional granite mineral filler.*

## Mechanical performance of **asphalt** mixtures modified by bio-oils derived from waste wood resources

[X Yang](#), [Z You](#), [Q Dai](#), [J Mills-Beale](#) - *Construction and Building Materials*, 2014 - Elsevier

... In this study, the **asphalt pavement** analyzer (APA) test is conducted to analyze the rutting resistance of **asphalt** mixtures ... The presence of **biochar** in the bio-oil reduced the adhesive strength between aggregate and BOM **asphalt** binder ...

*The word "biochar" does not appear in the abstract.*

*The abstract*

*Bio-oils are thought to be potentials for petroleum asphalt binders used in asphalt pavement because of the renewability and environmental friendliness. The aim of this study is to investigate the performances of asphalt binders modified by bio-oils generated from waste wood resources. Three types of bio-oils generated from wood waste resources are used in this study: the original bio-oil (OB), de-watered bio-oil (DWB) and polymer modified bio-oil (PMB). OB, DWB and PMB were added into the base asphalt PG 58-28 at 5% and 10% by weight. The rotational viscometer (RV), dynamic shear rheometer (DSR), rolling thin film oven (RTFO), pressure aging vessel (PAV) and bending beam rheometer (BBR) were conducted to evaluate the rheological properties of bio-oil modified asphalt binders. The Superpave™ binder specification was used to evaluate the performances of bio-oil modified asphalt binders. The test results show that the addition of bio-oil can lower the mixing temperature of asphalt mixtures while improving the high temperature performance of asphalt binders. However, the medium and low temperature performances were sacrificed. Comparison among the three types of bio-oil modified asphalt binders showed that PMB modified asphalt binders had the highest stiffness, followed by the DWB and OB modified binders. The OB had the lowest effect on the base asphalt binder compared to other two types of bio-oils.*

[PDF] [researchgate.net](#)

## Flow-induced crystallization of **biochar** in bio-**asphalt** under various aging conditions

[X Zhou](#), [S Adhikari](#) - *Science of The Total Environment*, 2019 - Elsevier

... The **pavement** properties and durability of styrene-butadiene styrene (SBS) modified bio-**asphalt** were also ... The one main component of pyrolysis products of waste wood is **biochar** that its ... component is carbon that could shield the ultraviolet light of the **asphalt** surface, prevent ...

*From the abstract:*

*Small angle X-ray scattering and molecular dynamic simulations were performed to impose extensional deformation and the nucleation process. The rheological properties were measured using the dynamic shear rheometer (DSR) and the morphology of biochar modified bio-asphalt (BMBA) was measured using an optical microscope. The relative scattering intensity during crystallization appeared to peak at four strain rates: 13.2 s<sup>-1</sup>, 19.6 s<sup>-1</sup>, 25.4 s<sup>-1</sup>, and 27.3 s<sup>-1</sup>. The results showed*

*that the addition of biochar could improve the flow-induced crystallization and enhance the high-temperature properties of bio-asphalt.*

## Evaluation of low-temperature binder properties of warm-mix **asphalt**, extracted and recovered RAP and RAS, and bioasphalt

[Z You, J Mills-Beale, E Fini, SW Goh...](#) - Journal of materials in ..., 2011 - ascelibrary.org

... Bioresource and **pavement** engineers are investigating the use of nontraditional materials such as feedstock for the new generation of **asphalt** binder used in ... to elevated temperatures and high pressures in the absence of oxygen in order to produce **biochar**, mainly bio oil ...

*The word "biochar" does not appear in the abstract.*

*From the abstract:*

*Bioasphalt was produced from swine waste ....*

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## A systematic review of bio-**asphalt** for flexible **pavement** applications: Coherent taxonomy, motivations, challenges and future directions

[AM Al-Sabaeei, MB Napiah, MH Sutanto...](#) - Journal of Cleaner ..., 2020 - Elsevier

... Meanwhile, an extensive taxonomy was developed based on the literature reviewed and analysed in terms of pure bio-**asphalt** binder, biomaterials with warm mix **asphalt**, biomaterials with reclaimed **asphalt pavement** and biomaterials with capsulation technology ...

*The word "biochar" does not appear in the abstract.*

*The abstract:*

*From the perspective of highway engineering, bio-asphalt binders have economic, social and environmental benefits and, therefore, can be partially substituted for petroleum-based asphalt binders. A typical raw material for producing bio-asphalt binder used as a renewable energy source is commonly called a biomaterial. Examples of these biomaterials are swine manure and waste cooking oil, as well as castor, sunflower, cotton, linseed and soybean oils. The aim of this review was to survey research efforts on bio-asphalt binder technology for flexible road applications, map the research view from the literature into a coherent and systematic taxonomy and determine the motivations behind using biomaterials in road applications. Meanwhile, an extensive taxonomy was developed based on the literature reviewed and analysed in terms of pure bio-asphalt binder, biomaterials with warm mix asphalt, biomaterials with reclaimed asphalt pavement and biomaterials with capsulation technology. Moreover, critical rheological characteristics and their performance characteristics in bio-asphalt mixture applications were reviewed. The current review concluded that most of the biomaterials can improve the low-temperature rheological properties, but at the same time affect the high-temperature rheological properties. The ageing of most bio-asphalt binders was also found to have a negative effect on the performance of bio-asphalt based on feedback sources and the resulting by-products, which cause unstable physicochemical and morphological behaviours. The fatigue performance of most of the bio-asphalt mixtures was positively enhanced, whereas rutting and moisture resistance were negatively affected. Overall, the different types of bio-asphalt binders possess properties that are either positive or negative. Future research is recommended to mitigate the ageing properties of bio-asphalt binders. The environmental impact and life-cycle assessment of bio-asphalt and traditional petroleum-based asphalt binders must be compared. Determining the optimum biomaterials to be used in pavement applications without compromising performance is an interesting task. This systematic review is expected to contribute to understanding of available gaps and options for other interested researchers to participate in this line of research.*

## Bioasphalt and **Biochar** from Pyrolysis of Urban Yard Waste

DR Hill - 2012 - [rave.ohiolink.edu](http://rave.ohiolink.edu)

... multiple products: **biochar** (a solid product) and bio-oil (a liquid product). **Biochar** can be ... Bio-oil consists of viscous organics which can have a variety of applications, including the potential use as a non-petroleum-based **asphalt pavement** binder. Both of these products ...

*From the abstract:*

*Pyrolysis of yard waste biomass creates both biochar, a carbon-sequestering soil amendment, and bio-oil, a viscous liquid that could be used as a renewable source for non-petroleum-based asphalt binders.*

### Performance Evaluation of Asphalt Binder Modified by Bio-oil Generated from Waste Wood Resources.

<https://trid.trb.org/view/1259485>

X Yang, Z You, Q Dai - International Journal of **Pavement Research** & ..., 2013 - academia.edu

... Recycling **asphalt pavement** (RAP) material is an effective way to reduce the usage of fresh ... is to find alternative materials that can partially or fully replace the petroleum **asphalt** ... this process, three main components are generated, the organic vapor, pyrolysis gases and **biochar** ...

*The word "biochar" does not appear in the abstract.*

*The abstract:*

*Bio-oils are thought to be potentials for petroleum asphalt binders used in asphalt pavement because of the renewability and environmental friendliness. The aim of this study is to investigate the performances of asphalt binders modified by bio-oils generated from waste wood resources. Three types of bio-oils generated from wood waste resources are used in this study: the original bio-oil (OB), de-watered bio-oil (DWB) and polymer modified bio-oil (PMB). OB, DWB and PMB were added into the base asphalt PG 58-28 at 5% and 10% by weight. The rotational viscometer (RV), dynamic shear rheometer (DSR), rolling thin film oven (RTFO), pressure aging vessel (PAV) and bending beam rheometer (BBR) were conducted to evaluate the rheological properties of bio-oil modified asphalt binders. The Superpave™ binder specification was used to evaluate the performances of bio-oil modified asphalt binders. The test results show that the addition of bio-oil can lower the mixing temperature of asphalt mixtures while improving the high temperature performance of asphalt binders. However, the medium and low temperature performances were sacrificed. Comparison among the three types of bio-oil modified asphalt binders showed that PMB modified asphalt binders had the highest stiffness, followed by the DWB and OB modified binders. The OB had the lowest effect on the base asphalt binder compared to other two types of bio-oils.*

### Biochar products and production

SC Weaver, DL Hensley, J Bierkamp, N Evans... - US Patent ..., 2018 - Google Patents

... Some embodiments include configuring the produced **biochar** as a modifier for **asphalt**. Configuring the produced **biochar** as the **asphalt** modifier may include mixing the produced **biochar** with the **asphalt** ... **Asphalt** may be mixed with the **biochar** product ...

*The word "biochar" does not appear in the abstract of this patent.*

*From the summary:*

*Some embodiments include configuring the produced biochar as activated carbon. Some embodiments include configuring the produced biochar as a modifier for asphalt. Configuring the produced biochar as the asphalt modifier may include mixing the produced biochar with the asphalt.*

### Rheological Performance of Bio-Char Modified Asphalt with ...

Sep 15, 2018 - Furthermore, the **asphalt** binder modified by the bio-char with sizes less ... might have contributed to the form of a strong **biochar**-binder matrix ...

by R Zhang - 2018 - [Cited by 4](#) - [Related articles](#)

*From the abstract:*

*The rheological properties of bio-char modified asphalt binders were compared with different particle sizes and contents, with one control and one flake graphite modified asphalt binder. Specifically, the*

*bio-char modifiers with two particle sizes (ranging from 75  $\mu\text{m}$ –150  $\mu\text{m}$  and less than 75  $\mu\text{m}$ ) and three contents of 2%, 4%, and 8% were added into the asphalt binder. A flake graphite powder with particle sizes less than 75  $\mu\text{m}$  was used as a comparison modifier. The Scanning Electron Microscopy (SEM) image showed the porous structure and rough surface of bio-char as well as dense structure and smooth surface of flake graphite. A Rotational Viscosity (RV) test, Dynamic Shear Rheometer (DSR) test, aging test, and Bending Beam Rheometer (BBR) test were performed to evaluate the properties of bio-char modified asphalt in this study. Both modifiers could improve the rotational viscosities of the asphalt binders. The porous structure and rough surface of bio-char lead to larger adhesion interaction in asphalt binder than the smooth flake graphite. As a result, the bio-char modified asphalts had better high-temperature rutting resistance and anti-aging properties than the graphite modified asphalt, especially for the binders with the smaller-sized and higher content of bio-char particles. Furthermore, the asphalt binder modified by the bio-char with sizes less than 75  $\mu\text{m}$  and about 4% content could also achieve a better low-temperature crack resistance, in comparison to other modified asphalt binders.*

## Rubberized Biochar used as Bitumen additive - Rail ...

PDF

The utilization of nanotechnology in **asphalt** industry is expected to increase and may become an alternative for **asphalt** binder modifications. The purpose of this ...

*From the abstract:*

*Modified bitumen samples were produced by mixing base bitumen with rubberized biochar at various additive content. The conventional properties of the modified binder were evaluated in terms of their rheological and physical properties. The outcome of this paper indicated that the addition of rubberized biochar was helpful in increasing the failure temperature, complex modulus and elastic modulus values and improving rutting resistance of the aged rubberized biochar modified binder. Due to its carbon nature and morphology the rubberized biochar has a twofold impact on the properties of bitumen, namely: it acts as an antioxidant thus retarding the ageing properties of bitumen and secondly it stiffens the bitumen by increasing its rheological (flow) properties.*

## Novel **biochar**-concrete composites: Manufacturing, characterization and evaluation of the mechanical properties

A Akhtar, [AK Sarmah](#) - Science of the total environment, 2018 - Elsevier

... For instance, study by Zhao et al. (2014) showed that **biochar** can be an effective **asphalt** binder as compared to commercially available carbon binders containing high surface area. **Biochar** improved the rutting resistance under ...

*From the abstract:*

*The word "asphalt" does not appear in the abstract.*

*Based on the findings, we conclude that biochar has the potential to improve the concrete properties while replacing the cement in minor fractions in conventional concrete applications.*

## [HTML] Special Issue on Innovation on Paving Materials

X Shu, [J Liu](#), [B Huang](#) - 2017 - ascelibrary.org

... in **pavement** construction (Aziz et al. 2015; Huang et al. 2012). Some examples of **asphalt** alternatives include bioasphalt derived from waste cooking oil (Wen et al. 2013), waste engine oil (Jia et al. 2014, 2015), and **biochar** derived from bio-oil used as a biomodifier for **asphalt** ...

*From the abstract:*

*This special issue contains eight technical papers in this area, which cover the topics of alternative paving materials, recycled asphalt pavement (RAP) and recycled asphalt shingles (RAS), new and innovative methods for evaluating the distress of asphalt and concrete materials, as well as the latest advances in pavement base construction and railroad ballast research.*

## [Bridging gaps between micro and mesoscale properties of Biochar](#)

*From the abstract:*

*Bio-mass derived byproducts are currently scrutinized as environmentally friendly substitutes for fine aggregates in cementitious and asphaltic composites, promoting the conservation of dwindling non-renewable resources. Nonetheless, no definite framework or guidelines exist for the methods to predict and assess the performance of such composites with respect to various criteria including structural, mechanical, durability, comfort and esthetics, environmental and economic impact. This paper aims at introducing different testing techniques for the examination of a new green material named biochar, a byproduct of the pyrolysis of Municipal Solid Waste (MSW), as a sustainable replacement of fine aggregates in construction materials, cementitious mortar in specific.*

## Experimental determination of the optimum percentage of **asphalt** mixtures reinforced with Nano-carbon black and polyester fiber industries

[B Mirbaha, A Abdi, M Zarei...](#) - Engineering Solid ..., 2017 - [growingscience.com](#)

... Performance characteristics of fiber modified **asphalt** concrete mixes. International Journal on **Pavement Engineering & Asphalt Technology**, 15(1), 38-50 ... Zhao, S., Huang, B., Shu, X., & Ye, P. (2014). Laboratory investigation of **biochar**-modified **asphalt** mixture ...

*The word 'biochar' appears only in the references.*

*From the abstract:*

*Cracking and degradation is common mode of failure in asphalt pavements that occurs due to increasing traffic loads or even environmental conditions. For facing with these damages, some solutions are proposed including correction, quality improvement and increasing the asphalt resistance. In this research, by adding different percent amounts of black nano-carbon and polyester fibers as modifier in the asphalt mixtures and conducting several Marshall tests, it was observed that adding these two additives can improve generally the Marshall results.*

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## Mechanical performance of **asphalt** mixture containing nano-charcoal coconut shell ash

[SNA Jeffry, RP Jaya, NA Hassan, H Yaacob...](#) - ... and Building Materials, 2018 - Elsevier

... The **asphalt pavement** is a type of road infrastructure that enables vehicles to travel from one place to another ... However, the service provided by **asphalt pavement** decreases with time due to the increased of traffic loading and sensitivity of bitumen towards temperature ...

*The word 'biochar' does not appear in the abstract.*

*From the abstract:*

*Bitumen modification by nanomaterials is a method that can enhance the performance of asphalt mixtures due to the large surface area and small size (1–100 nm) of nanomaterials. Therefore, this research was focused on the influence of nano-charcoal coconut shell ash (NCA)-modified bitumen towards the engineering properties of asphalt mixtures.*

## Use of **biochar** as carbon sequestering additive in cement mortar

[S Gupta, HW Kua, CY Low](#) - Cement and concrete composites, 2018 - Elsevier

... 2. Use of **biochar** as construction material. Over the past few years, **biochar** has received increasing attention as **pavement** and building construction material [[12], [13], [14], [15], [16], [17], [84], [85]]. For example, Gupta and Kua ...

*The word 'asphalt' does not appear in the abstract.*

*From the abstract:*

*The experimental results suggested that biochar addition can impart ductility to mortar under flexure, although flexural strength was not significantly influenced. Water penetration and sorptivity of mortar was significantly reduced due to addition of biochar, which indicate higher impermeability in biochar added mortar. However, it is found that addition of fresh biochar offers significantly higher mechanical strength and improved permeability compared to biochar saturated with carbon dioxide.*

## Aging influence on rheology properties of petroleum-based **asphalt** modified with biobinder

[J Mills-Beale, Z You, E Fini, B Zada...](#) - Journal of Materials in ..., 2014 - ascelibrary.org

... paving industry to fully embrace bioasphalts for use in highway and airport **pavement** construction ...

in either acetone or acetone and toluene mixtures and filtered to separate **biochar** (**biochar** is approximately ... C. The biobinder was then mixed with the PG 64-22 **asphalt** binder at ...

*The word 'biochar' does not appear in the abstract.*

*From the abstract:*

*This paper aims to investigate the viability of using swine waste binder to improve the rheological properties of bituminous asphalt binder.*

## A conceptual study on the formulation of a permeable reactive **pavement** with activated carbon additives for controlling the fate of non-point source environmental ...

[S Huang, C Liang](#) - Chemosphere, 2018 - Elsevier

... To take advantage of the road **pavement** network where non-point source (NPS) pollution such as benzene, toluene, ethyl-benzene, and xylene (BTEX) from vehicle traffic exhaust via wet and dry atmospheric deposition occurs, the **asphalt pavement** may be used as a media to ...

*The term 'activated carbons' appears in the abstract while 'biochar' does not.*

*From the abstract:*

*An experiment to prepare an adsorptive porous reactive pavement (PRP) was initiated to explore the potential to reduce environmental NPS vehicle pollution. The PRP was prepared and studied as follows: various activated carbons (AC) were initially screened to determine if they were suitable as an additive in the porous asphalt mixture; various mixtures of a selected AC were incorporated with the design of porous asphalt concrete (PAC) to produce PRP, and the PRP formulations were tested to ensure that they comply with the required specifications; qualified specimens were subsequently tested to determine their adsorption capacity for BTEX in aqueous solution, as compared to conventional PAC.*

## [PDF] An Overview on Using the Chicken Manure (CM) Waste as a Bio-binder for Sustainable Flexible **Pavement**

[AM Al-Sabaei, M bin Napiah, MH Sutanto, WS Alaloul...](#) - ripublication.com

... production of the bio-fuel especially bio- oil and **biochar** has the direct positive effects on the bio-**asphalt** materials can be applied for flexible road construction since the **asphalt** is one of the fuel derived materials, that will reduce the higher cost of the **asphalt pavement** such as ...

*From the abstract:*

*This paper introduces the bio-oil and bio-char by-products derived from the chicken manure (CM) waste materials as a bio-binder for flexible road construction.*

## Laboratory Evaluation of **Asphalt Cement and Mixture Modified by Bio-Char Produced through Fast Pyrolysis**

[S Zhao, B Huang, P Ye](#) - **Pavement Materials, Structures, and ...**, 2014 - [ascelibrary.org](#)

... "Stability of **biochar** in soil." In **Biochar** for Environmental Management: Science and Technology; Earthscan: Sterling, VA: 183-205 ... "Laboratory performance evaluation of warm-mix **asphalt** containing high percentages of reclaimed **asphalt pavement**." Transportation Research ...

*From the abstract:*

*The binder samples, made by incorporating bio-char into one commonly used asphalt binder in the U.S., were tested for their rheological characteristics, rutting, and fatigue performance. It was found that bio-char was capable of significantly increasing the rutting resistance of the asphalt binder. The fatigue and cracking resistance was little affected by modification. The modified HMA mixture showed better resistance in rutting, moisture damage and cracking.*

## Performance Evaluation of Carbon Black Nano-Particle Reinforced **Asphalt Mixture**

[J Rafi, MA Kamal, N Ahmad, M Hafeez...](#) - **Applied Sciences**, 2018 - [mdpi.com](#)

... Midpoint aggregate gradation of National Highway Authority (NHA) class B (19.5 mm nominal maximum aggregate size) was used in this study. It is specified as a finer gradation and is generally used by the local **pavement** industry as an **asphalt** wearing course ...

*The word 'biochar' does not appear in the abstract.*

*From the abstract:*

*Conventional asphalt binder generally does not provide sufficient resistance against rutting at high temperatures. Carbon black nano-particles (CBNPs, produced by perennial mountain trees' carbonization) were mixed into the performance grade (PG) 58 asphalt binder in this study. Conventional asphalt binder tests (penetration, ductility and softening point), frequency sweep, performance grading, and bitumen bond strength tests were conducted to study the enhancement in the properties of asphalt binder. Dynamic modulus and wheel tracking tests were also performed to investigate the effect of CBNPs on asphalt mixture properties. Experimental results demonstrated that preferred dosage of CBNPs in asphalt is 10% by weight of the bitumen. Results of scanning electron microscopy (SEM) and storage stability tests validated homogenous and stable dispersion of CBNPs in the asphalt binder. Asphalt mixtures became stiffer and resistant to rutting at high temperatures by addition of CBNPs in asphalt binder. Significant improvement in bitumen aggregate bond strength was also observed by incorporating CBNPs. It is concluded that CBNPs can be used to effectively enhance the high-temperature performance and consequently the sustainability of flexible pavements*

## Research on properties of bio-**asphalt** binders based on time and frequency sweep test

[J Gao, H Wang, Z You, MRM Hasan](#) - **Construction and Building Materials**, 2018 - Elsevier

... 89-103. Google Scholar. [2] HN Wang, JF Gao, ZP You, et al. Advances in bio-binder application on road **pavement**. J. Wuhan Univ ... 52-62. Google Scholar. [5] S. Zhao, BS Huang, X. Shu, et al. Laboratory investigation of **biochar**-modified **asphalt** mixture. Transp. Res. Rec ...

*The word 'biochar' does not appear in the abstract.*

*From the abstract:*

*Bio-asphalt is a binding agent that is made of bio-oil and petroleum asphalt, or bio-oil modified with incorporations of some other additives under certain conditions. This study was carried out to evaluate the properties of bio-asphalt binder-based in terms of the value of complex shear modulus ( $G^*$ ) and the phase angle ( $\delta$ ) tested by dynamic shear rheometer (DSR).*

### [PDF] A review of performance **asphalt** mixtures using bio-binder as alternative binder

R Mamat, MR Hainin, NA Hassan, NAA Rahman... - Jurnal ..., 2015 - eprints.utm.my

... 5][6]. Utilize this biomass can be a great potential as modifier for **asphalt** binder because ... which is a thermal–chemical process that converts organic materials into solids (**biochar**) and volatiles ... study the applicability of using the bio- oils as bio-binder in the **pavement** industry[20 ...

*The word 'biochar' does not appear in the abstract. It appears just once in the full text in reference to the products of pyrolysis.*

*From the abstract:*

*This paper provides an overview of the performance in asphalt mixture using bio-binder from biomass as alternative binder. The bio-binder considered from the previous research was produced by pyrolysis process. The aim of this study is to review the performance of asphalt mixture modified by bio-binder. ....*

*Therefore, in many of these case the bio-binder was evaluated in minimal proportions (<10 percent). This is necessary in order to identify a mixtures containing bio-binder at higher blending proportions (up to 50% replacement).*

### [PDF] An overview of utilization of bio-oil in hot mix **asphalt**

S Tayh, R Muniandy, S Hassim, F Jakarni, E Aburkaba - WALIA journal, 2014 - waliaj.com

... The dynamics of world resource economics suggest that all industries, including the **asphalt pavement** industry, should be exploring economically, socially, and environmentally sustainable approaches to development. Increased ...

*The word 'biochar' appears only in the references.*

*From the abstract:*

*The asphalt industry is constantly attempting to reduce its emissions as concerns are growing on global warming. This is done by decreasing the mixing and compaction temperatures of asphalt mixtures without affecting the properties of the mix which is possible through numerous available technologies in the industry. One of these techniques is by using bio-oil technology as a modifier or an extender of the base asphalt binder in pavement mixtures.*

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### A review on the application of bio-oil as an additive for **asphalt**

NAA Raman, MR Hainin, NA Hassan... - Jurnal ..., 2015 - jurnalteknologi.utm.my

... Synthesis and Characterization of Biomodified Rubber **Asphalt**: Sustainable Waste Management Solution ... Road Materials and **Pavement** Design Thermo-mechanical behaviour of mixtures containing ... Technology Physicochemical Properties Of Bio-Oil and **Biochar** Produced by ...

*The word 'biochar' does not appear in the abstract. It appears just once in the full text in reference to the products of pyrolysis and once in the references.*

*From the abstract:*

*According to previous research, that has been developed that non crude petroleum binder derived from the production of bio-oil through fast pyrolysis of biomass. The main source of bio-oil can be contributed from biomass industry or renewable organic industry such as timber waste, oil palm waste, rice husk; coconut trunk fibers, municipal waste and sugar cane waste. Alternatively, the bio-oil can be as substitute material as modification of asphalt. This paper presents a review on the source, characteristic of bio-oil and the effects of bio-oil on the properties of asphalt bitumen.*

### Utilizing bio-char as a bio-modifier for **asphalt** cement: A sustainable application of bio-fuel by-product

S Zhao, B Huang, XP Ye, X Shu, X Jia - Fuel, 2014 - Elsevier

... fixed in **asphalt** rubber [13], [14], various polymeric **asphalt** modifiers [15], [16], [17] and sustainable **pavement** technologies [18 ... T400S10, Tube furnace **biochar**, 15, 400,  $d < 75 \mu\text{m}$ , 10 ... One commonly used **asphalt** binder with PG 64-22 was selected as the base binder in this study ...

*From the abstract:*

*In this study, bio-char derived from switchgrass through different types of pyrolysis were tested as bio-modifier for asphalt binder. A commercially activated carbon was utilized for comparison. All the carbonaceous additives were incorporated into one commonly used asphalt binder at different concentrations in order to obtain the optimal content. The samples were tested in the laboratory for their rheological characteristics, rutting and fatigue performance and ductility properties. Highest treatment temperature (HTT), pyrolysis method, particle size of bio-modifier and modifier content were investigated to achieve the optimal modification effect. It was found that bio-char was capable of reducing the temperature susceptibility and significantly increasing the rutting resistance of the asphalt binder. The addition of the bio-char showed little effect on the fatigue and cracking resistance, with the best fatigue and cracking resistance found on the bio-char with finer particles ( $\sim 75 \mu\text{m}$ ) produced at lower HTT (400 °C) and lower heating rate (15 °C/min). Based on the testing results, bio-char appears to be a more effective binder modifier than commercially activated carbon within addition of 10 wt.%.*

## Investigation of infiltration rate for soil-biochar composites of water hyacinth

[P Gopal](#), [S Bordoloi](#), [R Ratnam](#), [P Lin](#), [W Cai](#)... - Acta Geophysica, 2019 - Springer

... There is an increase in the significance of VWC in determining infiltration rate for soil-biochar composites compared to BS ... Based on National **Asphalt Pavement** Association (NAPA 2018), soils underlying a porous **pavement** should have a minimum infiltration rate of 0.50 inches ...

*The word 'asphalt' appears only in the references.*

*From the abstract:*

*The objective of this short communication is to investigate the interactive effects of CIF, suction and volumetric water content (VWC) on infiltration rate for compacted soil-biochar (BC) composites (0%, 5% and 10%). The biochar was produced from an invasive weed Eichhornia crassipes. Soil parameters such as suction ( $\psi$ ), VWC, CIF and infiltration rate were monitored simultaneously for 63 days (9 drying-wetting cycles) in those composites.*

## Formulation and aging resistance of modified bio-asphalt containing high percentage of waste cooking oil residues

[D Sun](#), [T Lu](#), [F Xiao](#), [X Zhu](#), [G Sun](#) - Journal of Cleaner Production, 2017 - Elsevier

... Bio-**asphalt** is a sustainable **pavement** material which is produced by bio-oils after blending, oxidation and other technology ... Biomass materials are converted to fuel gases, bio-oil and **biochar** after the thermal-chemical process ...

*The word 'biochar' does not appear in the abstract*

*From the abstract:*

*Waste cooking oil residues (WCOR) based bio-asphalt is a potential substitute for petroleum asphalt. This study aims to prepare a bio-asphalt with high percentage of WCOR derived from esterification reaction for biodiesel.*

## Biochar products and production

[SC Weaver](#), [DL Hensley](#), [J Bierkamp](#)... - US Patent App. 15 ..., 2018 - Google Patents

... US 2018305621 A1 US2018305621 A1 US 2018305621A1 Authority US United States Prior art keywords **biochar** embodiments seconds ... 241000196324 Embryophyta Species 0 description 19; 239000010426 **asphalt** Substances 0 description 19; 238000004089 heat treatment ...

*The word 'asphalt' does not appear in the abstract. It appears in some of the embodiments described in this patent ( US20180305621A1)*

*From the abstract:*

*Tools and techniques for biochar production and biochar products are provided in accordance with various embodiments. For example, some embodiments include a method of biochar production that may include introducing a compound that includes at least carbon, oxygen, and hydrogen into a reaction chamber.*

## Chemical characterization and oxidative aging of bio-asphalt and its compatibility with petroleum asphalt

[X Yang](#), [J Mills-Beale](#), [Z You](#) - Journal of Cleaner Production, 2017 - Elsevier

... S BN Solubility number. TB Treated bio-oil. 1. Introduction. **Asphalt pavement** engineers and researchers have been seeking materials that would guarantee the structural integrity and performance of **asphalt pavement** without compromising the environment ...

*The word 'biochar' does not appear in the abstract.*

*From the abstract:*

*The objective of this paper is to characterize the elemental composition, chemical compounds, oxidative aging and the compatibility of bio-asphalt modified with bio-oil. A petroleum asphalt was modified with treated and untreated bio-oil at 2%, 5% and 10% by weight to prepare bio-asphalt, respectively.*

## Production, Characterization and Alternative Applications of Biochar

A Ngan, [CQ Jia](#), [ST Tong](#) - Production of Materials from Sustainable ..., 2019 - Springer

... Production of Materials from Sustainable Biomass Resources pp 117-151 | Cite as. Production, Characterization and Alternative Applications of **Biochar** ... Finally, alternative applications of **biochar** are highlighted. 5.2 Production of **Biochar** ...

*The word 'asphalt' appears only in one reference..*

*From the abstract:*

*In this chapter, a state-of-the-art overview in biochar production, characterization and applications in non-traditional areas is given. On the production side, the emphasis is on pyrolysis – the primary production method, specifically the effects of pyrolysis conditions on biochar yield and characteristics. Characterization methods include ones for both pores and carbon matrix in biochar, such as pore size distribution, surface chemistry, morphology, crystallinity and bonding structure.*

## Evaluation of the Rheological Properties of Bituminous Binders Modified with Biochars Obtained from Various Biomasses by Pyrolysis Method

[ME Çeloğlu](#), [M Yılmaz](#) - International Journal of Urban and ..., 2020 - publications.waset.org

... Additionally, with **biochar** additive, it was determined that the rutting parameter values obtained from ... Z. You, B. Zada, JM Beale, "Partial Replacement of **Asphalt** Binder with Bio-Binder: Characterisation and Modification", International Journal of **Pavement** Engineering, 2012 ...

*The word 'asphalt' appears only in the references.*

*From the abstract:*

*In this study, apricot seed shell, walnut shell, and sawdust were chosen as biomass sources. The materials were sorted by using a sieve No. 50 and the sieved materials were subjected to pyrolysis process at 400 °C, resulting in three different biochar products. The resulting biochar products were added to the bitumen at three different rates (5%, 10% and 15%), producing modified bitumen. Penetration, softening point, rotation viscometer and dynamic shear rheometer (DSR) tests were conducted on modified binders. Thus the modified bitumen, which was obtained by using additives at 3 different rates obtained from biochar produced at 400 °C temperatures of 3 different biomass sources were compared and the effects of pyrolysis temperature and additive rates were evaluated.*

## [\[PDF\] Performance comparison between different sourced bioasphalts and asphalt mixtures](#)

[Z Dong](#), [T Zhou](#), [H Wang](#), H Luan - Journal of Materials in Civil ..., 2018 - researchgate.net ... strength inside the blended **asphalt** binder due to the formation of **biochar** during the mixing of **asphalt** mixture with bio-oil through short-term aging. Mogawer et al. (2016) used bio-oil as a modifier for an **asphalt** mixture incorporating 40% reclaimed **asphalt pavement** (RAP) ...

*The word 'biochar' does not appear in the abstract.*

*From the abstract:*

*The bio-modification was performed by modifying a virgin asphalt binder with a bio-binder produced from swine manure.*

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Page 5

## Fractional viscoelastic study of low-temperature characteristics of biomodified **asphalt** binders

[EH Fini](#), [A Khodaji](#), [P Hajikarimi](#) - Journal of Materials in Civil ..., 2016 - ascelibrary.org ... used to modify or partially replace the petroleum-based **asphalt** binders in the **asphalt pavement** structure ... remaining in the reactor was weighed to provide the percentage of **biochar** in each ... Biomodified binders were produced by blending each bio-oil with neat **asphalt** binder ...

*The article seems to refer to bio-oils, not to biochar.*

*From the abstract:*

*Therefore, the current paper implements a fractional viscoelastic approach to study the effectiveness of several bio-based modifiers on improving asphalt binder's low-temperature characteristics. As such, implementing the bending beam rheometer (BBR) test, low-temperature rheological characteristics of asphalt binders, which are modified by four different bio-oils including biobinder from swine manure, corn stover, wood pellet, and miscanthus pellet are investigated.*

## **Biochar** methods, systems, devices, and products

SC Weaver - US Patent App. 15/873,052, 2018 - Google Patents ... US 2018280906 A1 US2018280906 A1 US 2018280906A1 Authority US United States Prior art keywords **biochar** embodiments objects ... 239000002956 ash Substances 0 description 11; 239000010426 **asphalt** Substances 0 description 14; 230000000386 athletic Effects 0 ...

*The word 'asphalt' appears in some of the embodiments of this patent US20180280906A1*

*From the abstract:*

*Tools and techniques for biochar method, systems, devices, and products are provided in accordance with various embodiments. For example, methods are provided in accordance with various embodiments that may include rubbing one or more objects with biochar.*

## Experimental study on the vegetation characteristics of **biochar**-modified vegetation concrete

M Zhao, Y Jia, L Yuan, J Qiu, C Xie - Construction and Building Materials, 2019 - Elsevier ... organisms. The application of **biochar** in other building materials has also shown positive results. For example, as a modifier for **asphalt** cement, **biochar** has improved anti-aging performance and relieved temperature sensitivity [34] ...

*From the abstract:*

*Vegetation concrete is an effective material to beautify the landscape, reduce pollution and protect the environment. To further improve the plant compatibility of vegetation concrete, this paper recommends an improved method of adding biochar particles to vegetation concrete. In this research, different masses of biochar were mixed into concrete to study the trend in porosity, permeability and plant compatibility.*

## Evaluation of **asphalt** effect on water quality using leaching test and molecular simulation

J Chen, [H Wang](#), J Wu, [G Xu](#) - Journal of Testing and Evaluation, 2018 - [astm.org](#)

... Previous studies have reported that volatile organic content (VOC) can be generated during field operations of **asphalt pavement** construction at high temperatures, causing atmospheric pollution [1,2]. Besides, because rainfalls run off **pavement** over time, **asphalt** components ...

*The word 'biochar' does not appear in the abstract.*

*From the abstract:*

*The contact of water and asphalt in roadway pavement can lead to the leaching of components from asphalt and cause water contamination. In order to study influencing factors affecting water contamination caused by asphalt materials, leaching tests were performed on asphalt mixture specimens with different mix designs. Chemical oxygen demand (COD), pH value, and total hardness are used to evaluate the leachability of asphalt mixture.*

## Biochar as a carbon sequestering construction material in cementitious mortar

S Gupta, [HW Kua](#) - Academic Journal of Civil Engineering, 2017 - [journal.augc.asso.fr](#)

... application of **biochar** beyond just soil enhancement, Canadian **Biochar** Initiative encouraged its use in several other industrial areas including **asphalt** and concrete industry. **Biochar** has attracted research attention as a potential construction material in **pavement** and building ...

*The word 'asphalt' does not appear in the abstract.*

*From the abstract:*

*Our study focuses on application of biochar derived from mixed-wood saw dust as a cement replacement in mortar. Experimental findings suggest that, due to its fine particle size and microfiller effect, up to 4% cement replacement by biochar yielded slight improvement in compressive strength while reducing sorptivity by about 70% after 28 days. Improvement in strength and permeability of mortar by incorporating biochar suggest that it can be successfully deployed as a carbon sequestering concrete construction material.*

## [PDF] Development and characterization of novel **biochar**-mortar composite utilizing waste derived pyrolysis **biochar**

[K Roy](#), [A Akhtar](#), [S Sachdev](#), [M Hsu](#), [J Lim](#)... - ... Journal of Scientific & ..., 2017 - [researchgate.net](#)

... Int. J. **Pavement** Eng ... [18] Lee, S., Gupta, P., Ann, T., Lee, S., 2016. Use of **Biochar** to Enhance

Constructed Wetland Performance in Wastewater Reclamation ... Utilizing bio-char as a bio-modifier for **asphalt** cement: a sustainable application of bio- fuelby-product.Fuel133:52–62 ...

*The word 'asphalt' does not appear in the abstract.*

*From the abstract:*

*Three major tests were used to analyze cement-biochar composite. The tests are compressive strength test, Fourier transform infrared spectroscopy (FTIR) and water absorbance test.*

## Coal-tar-based **pavement** sealcoat and PAHs: implications for the environment, human health, and stormwater management

BJ Mahler, [PCV Metre](#), [JL Crane](#), [AW Watts](#)... - 2012 - ACS Publications

... The **asphalt pavement** of many parking lots, driveways, and even some playgrounds in North America is sprayed or painted with a black, shiny coating referred to as “sealcoat,” “**pavement** sealant,” or “driveway sealer” (Figure 1A). Sealcoat is marketed as improving **pavement** ...

*The words 'biochar' and asphalt' appear only in the references.*

*From the abstract:*

*Coal-tar-based sealcoat products, widely used in the central and eastern U.S. on parking lots, driveways, and even playgrounds, are typically 20–35% coal-tar pitch, a known human carcinogen*

*that contains about 200 polycyclic aromatic hydrocarbon (PAH) compounds. Research continues to identify environmental compartments—including stormwater runoff, lake sediment, soil, house dust, and most recently, air—contaminated by PAHs from coal-tar-based sealcoat and to demonstrate potential risks to biological communities and human health. In many cases, the levels of contamination associated with sealed pavement are striking relative to levels near unsealed pavement: PAH concentrations in air over pavement with freshly applied coal-tar-based sealcoat, for example, were hundreds to thousands of times higher than those in air over unsealed pavement. Even a small amount of sealcoated pavement can be the dominant source of PAHs to sediment in stormwater-retention ponds; proper disposal of such PAH-contaminated sediment can be extremely costly. Several local governments, the District of Columbia, and the State of Washington have banned use of these products, and several national and regional hardware and home-improvement retailers have voluntarily ceased selling them.*

### [PDF] Thermal storage stability of bio-oil modified asphalt

[R Zhang, H Wang, X Jiang, Z You, X Yang...](#) - J. Mater. Civ. Eng, 2018 - researchgate.net  
... of three bio-oil modified asphalts mixtures for mixtures containing reclaimed **asphalt pavement** (RAP ... in accordance with the "Technical Specifications for Construction of Highway **Asphalt Pavements**" (Chinese ... decomposition into **biochar**, vapors, and aerosols (Bridgwater 2012 ...

*Biochar is mentioned only in passing. The focus is on the bio-oil.*

*From the abstract:*

*This study investigates and evaluates the storage stability of asphalt binder modified by bio-oil at high temperature. Five bioasphalts are prepared by adding 10, 15, 20, 25, and 30% bio-oil into 70# petroleum asphalt ..*

End of Section 1, 'first five pages' of results from Google Scholar.

## SECTION 2:

Here are the eight hits using "cold mix" in addition to the three-word search string in Section 1.

### [BOOK] ... in Materials and **Pavement** Prediction: Papers from the International Conference on Advances in Materials and **Pavement** Performance Prediction (AM3P ...

[E Masad, A Bhasin, T Scarpas, I Menapace, A Kumar](#) - 2018 - books.google.com

... & A. Gupta Bridging gaps between micro and mesoscale properties of **Biochar** mortar RN ... Sari Ad Din, NF Saleh, AA Zalgout & GR Chehab **Pavement** maintenance scheduling ... AT Papagiannakis, R. Kaphle & M. Khalili Mechanical performance of **cold mix asphalt** with bitumen ...

*Session15 includes : "Bridging gaps between micro and mesoscale properties of Biochar mortar" by R.N. Mrad & G.R. Chehab*

(This publication also appears in section 1.)

### Chemical characterization and oxidative aging of bio-asphalt and its compatibility with petroleum asphalt

[X Yang, J Mills-Beale, Z You](#) - Journal of Cleaner Production, 2017 - Elsevier

... S BN Solubility number. TB Treated bio-oil. 1. Introduction. **Asphalt pavement** engineers and researchers have been seeking materials that would guarantee the structural integrity and performance of **asphalt pavement** without compromising the environment ...

*The publication refers to bio-oil. Neither the word 'biochar' nor 'cold' appear in the abstract.*

## [HTML] ALTERNATIF PENGGUNAAN BATU PUTIH LOKAL SEBAGAI BAHAN PERKERASAN JALAN

P NGITA, E Widodo - ... : Jurnal Penelitian Teknik Sipil dan Teknik ..., 2017 - publikasi.unitri.ac.id

... Fifteenth. Edition. Washington,DC ASTM, 1997, Road and Paving Materials Vehicle – **Pavement** Systems, Published By The American Society of Testing Material ... The **Asphalt** Institute (1990), **Asphalt Cold Mix** Manual, Manual Series (MS) No.14, Third Edition, Maryland, USA ...

*From the abstract:*

## Enhancing Asphalt Binder's Rheological Behavior and Aging Susceptibility Using Nano-Particles

RC Walters - 2014 - search.proquest.com

... this study to create bio-modified **asphalt**. It should be noted that application of bio-binder enhances **pavement** sustainability while facilitating manure management. Swine manure ... **mix asphalt** (CMA) which reduce fuel consumption and CO2 production ...

*From the abstract:*

## Preparation and uses of bio-adhesives

EH Fini - US Patent 9,637,615, 2017 - Google Patents

... 032,445 US201314032445A US9637615B2 US 9637615 B2 US9637615 B2 US 9637615B2  
US 201314032445 A US201314032445 A US 201314032445A US 9637615 B2 US9637615  
B2 US 9637615B2 Authority US United States Prior art keywords bio **asphalt** cp viscosity ...

*From the abstract:*

## Preparation and uses of bio-adhesives

EH Fini - US Patent App. 16/126,354, 2019 - Google Patents

... In another variation, the present application discloses a method of sealing a crack or joint in **asphalt pavement** comprising applying ... be subjected to optional post-processing 122' to produce bio-binder 134' and bio-**asphalt** 136', in ... After filtration, removing **biochar** (108 in FIG ...

*From the abstract:*

## Preparation and uses of bio-adhesives

[EH Fini - US Patent 10,077,356, 2018 - Google Patents](#)

... After filtration, removing **biochar** (108 in FIG ... Typically, bio-rejuvenator inhibits processes leading to **pavement** degradation ... containing **asphalt** and aggregate, prepared using standard methods, including warm mix, semi-**cold mix**, **cold mix**, and hot mix **asphalt** technologies ...

*From the abstract:*

## Photonic radiolysis of waste materials

[DP Petry, AMHA Ayala, AAB Maciel... - US Patent 9,068,133, 2015 - Google Patents](#)

... with inert aggregates, which, depending on the mixing temperature, are classified into hot mix **asphalt** concrete and **cold mix asphalt** concrete. More than 90% of paved roads are executed with flexible pavements, so the technique used for said type of **pavement** is widely ...

*From the abstract:*