PHYSICAL AND MECHANICAL PROPERTIES OF POROUS ASPHALT INCORPORATING BAMBOO FIBER

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

FACULTY OF CIVIL ENGINEERING TECHNOLOGY

UNIVERSITI MALAYSIA PAHANG

JANUARY 2023

ACKNOWLEDGEMENTS

Alhamdulillah. Thanks to Almighty Allah SWT, whom with his willing giving me the opportunity to complete this master study.

Foremost, I would like to express my sincere gratitude to my honorable supervisor Dr. Khairil Azman Bin Masri for the continuous support of my master study and research, for his patience, motivation, enthusiasm and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my master study.

Besides my supervisor my sincere thanks also go to my co-supervisor Dr. Nadiatul Adilah Ahmad Abdul Ghani for offering me the inspirational spirit and the encouragement to work harder.

Last but not the least; I would like to thank my family: my parents for supporting me spiritually throughout my life.

ABSTRAK

Asfalt berliang (PA) merupakan campuran asfalt dengan permukaan yang sangat telap dimana berfungsi untuk membentuk dan mengekalkan turapan telap untuk pengurusan air hujan dan pengurangan air larian. Impak daripada beban kenderaan yang berulang, cuaca panas dan hujan lebat menyebabkan struktur turapan terdedah kepada masalah seperti keretakan, aluran, pelucutan dan penuaan yang pantas. Kajian ini bertujuan untuk mengkaji peranan gentian buluh untuk meningkatkan sifat fizikal, mekanikal dan morfologi serta mengatasi isu berkaitan asfalt berliang (PA). Spesimen PA yang mengandungi peratusan gentian buluh yang berbeza telah diuji untuk menilai sampel yang terbaik seperti yang dikehendaki. Dalam kajian ini tiga ujian prestasi fizikal iaitu (penyaliran pengikat, kebolehtelapan dan ujian cantabro) dan tiga ujian prestasi mekanikal (kestabilan marshall, modulus resilient dan ujian kekuatan tegangan tidak langsung) telah dijalankan untuk menentukan objektif kajian. Penyelidikan ini menggunakan dua jenis agregat Gred A dan B dengan empat peratusan gentian buluh yang berbeza (0.2%, 0.3%, 0.4%, 0.5%) dan juga sampel tanpa gentian buluh (0%) sebagai sampel terkawal. Dalam kajian ini, sebanyak 120 sampel PA digunakan di mana 96 ialah PA dengan gentian yang diubah suai dan 24 lagi ialah PA kawalan. Jumlah berat agregat setiap sampel ialah seberat 1100 g dan ketebalan purata setiap sampel adalah antara 66 mm hingga 70 mm. Dalam kajian ini juga, empat jenis gentian buluh yang berbeza peratusan telah dicampur dengan pengikat bitumen PEN 60/70. Ujian saliran pengikat dijalankan menggunakan bakul jaringan dawai yang diletakkan di dalam dulang. Keputusan menunjukkan bahawa 0% dan 0.5% mempunyai peratusan campuran bahan melepasi jaringan yang tertinggi, manakala 0.2% mempunyai peratusan campuran bahan melepasi jaringan terendah. Peratusan gentian buluh yang lebih rendah sesuai untuk PA. Sampel PA yang diubah suai 0.2 % gred B mempunyai kadar kebolehtelapan tertinggi (1.41m/s). Keputusan ini membuktikan kebolehan gentian buluh mampu meningkatkan kebolehtelapan PA. Berdasarkan kepada teori, semua sampel PA dengan pengubahsuaian buluh (0.2%, 0.3%, 0.4%, dan 0.5%) mempunyai hasil yang signifikan berbanding ujian prestasi fizikal yang lain. Sampel kawalan adalah dikecualikan. Semetara itu, ujian kestabilan Marshall untuk sampel PA dengan pengubahsuaian buluh 0.4% mencapai nilai purata kestabilan maksimum 9.842 kN untuk gred A dan 9.391 kN untuk gred B, berbanding sampel PA kawalan 0% iaitu 5.892 kN dan 8.545 kN. Setiap tempoh pengulangan nadi yang berbeza (tiga pengulangan nadi) untuk kedua-dua suhu (25℃ dan 40℃) dan gred (A dan B) 0.3% memperolehi nilai purata modulus ketahanan yang ideal (3156 MPa dan 2266 MPa). Bagi nilai kekuatan tegangan, nilai terbesar diperolehi oleh PA dengan pengubahsuaian buluh 0.3% iaitu 1.087 kPa untuk gred A dan PA dengan pengubahsuaian buluh 0.4% iaitu 0.961 kPa untuk gred B. Oleh itu, apabila gentian buluh digabungkan dengan PA, semua sifat ujian mekanikal menunjukkan peningkatan nilai yang ketara. Berdasarkan imej SEM, sampel kawalan menunjukkan lebih banyak rekahan berbanding PA dengan pengubahsuaian buluh. Pada masa yang sama, komponen kimia Silikon (Si) ditemui dalam kedua-dua imej EDX PA kawalan dan PA dengan pengubahsuaian buluh. Berdasarkan pada penemuan kajian ini, dapat disimpulkan bahawa kepekatan yang betul dan jumlah gentian buluh yang tepat boleh meningkatkan sifat fizikal dan mekanikal PA. Untuk kajian yang seterusnya, adalah dicadangkan bahawa pengaruh pelbagai panjang gentian buluh ke atas prestasi asfalt berliang perlu dikaji, ini termasuk pembangunan teknik reka bentuk yang sesuai untuk campuran PA yang akan menjadikan PA lebih berkualiti dan tahan lebih lama.

ABSTRACT

Porous Asphalt (PA) is a highly permeable asphalt surface used to create and maintain permeable pavements for storm water management and runoff reduction. Under the impacts of repetitive vehicle loads, warm weather, and heavily rainfall, the structure was vulnerable to deterioration from cracking, rutting, stripping, and quick aging. This research aims to investigate the role of bamboo fiber in improving the physical, mechanical and morphological properties and overcome the issue related to porous asphalt (PA). PA specimens containing different percentages of bamboo fiber were examined to see which samples offered the greatest performance according to the requirements. In this research three physical performance test which is (binder draindown, permeability and cantabro test) and three mechanical performance test (marshall stability, resilient modulus and indirect tensile strength test) was conducted to justify the study objective. This research used two types of aggregate Grade A and B with four different percentage of bamboo fiber (0.2%, 0.3%, 0.4%, 0.5%) and also a sample without bamboo fiber (0%) as the controlled sample. In this research 120 PA samples where 96 fiber modified PA and 24 control PA samples were used. The total aggregate weight was 1100 g for each sample, and the average thickness of each sample between 66 mm to 70 mm. In this research, four different percentages of bamboo fiber were mixed with PEN 60/70 bituminous binder. Binder drain-down test is conducted in a wire mesh placed inside the tray. The result indicated that 0% and 0.5% had the highest drain-down percentages and 0.2% had the lowest drain-down percentage. A lesser percentage of bamboo fiber is suitable for PA. Sample 0.2% modified PA grade B had the highest (1.41m/s) permeability coefficient value. This outcome supports the modified bamboo fiber greater PA value. According to the theory, all bamboo modified PA samples (0.2%, 0.3%, 0.4%, and 0.5%) had a significant outcome in comparison to the other physical performance tests. The control sample was the exception. Meanwhile, the marshall stability test bamboo modified 0.4% PA sample achieved a maximum stability average value of 9.842 kN for grade A and 9.391 kN for grade B, compared to the control 0% PA sample stability value of 5.892 kN and 8.545 kN. Every three-pulse repetitive period for both temperature (250℃ and 400℃) and grade (A and B) 0.3% obtained the ideal resilient modulus average value (3156 MPa and 2266 MPa). However, indirect tensile strength gains the greatest value at 0.3% bamboo modified PA, 1.087 kPa for grade A and 0.4% bamboo modified PA, 0.961 kPa for grade B. As a result, when bamboo fiber was combined with PA, all mechanical properties tests showed a significant value increase. Based on SEM images, the control sample showed more cracks in the contrast bamboo modified PA. On every occasion, a Silicon (Si) chemical component is found in both control and bamboo modified PA EDX images. From the findings, it can be concluded that proper concentration and exact subsistence of bamboo fiber can enhance PA physical and mechanical properties. For future research, it is suggested that the influence of various bamboo fibre lengths on porous asphalt performance is investigated, as well as the development of an acceptable design technique for PA mixtures that would provide PA with quality service history.

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REFERENCES

Aboufoul, M., Chiarelli, A., Triguero, I., & Garcia, A. (2019). Virtual porous materials to predict the air void topology and hydraulic conductivity of asphalt roads. *Powder Technology*, *352*, 294–304. https://doi.org/10.1016/j.powtec.2019.04.072

Ahmad, K. A., Abdullah, M. E., Abdul Hassan, N., Daura, H. A., & Ambak, K. (2017). A review of using porous asphalt pavement as an alternative to conventional pavement in stormwater treatment. *World Journal of Engineering*, *14*(5), 355–362. https://doi.org/10.1108/WJE-09-2016-0071

Ahmad, S. (2006). *Porous asphalt reduces storm water runoff | Asphalt magazine*. http://asphaltmagazine.com/porous-asphalt-reduces-storm-water-runoff/

Akhtar, M. N., Al-Shamrani, A. M., Jameel, M., Khan, N. A., Ibrahim, Z., & Akhtar, J. N. (2021a). Stability and permeability characteristics of porous asphalt pavement: An experimental case study. *Case Studies in Construction Materials*, *15*(June), e00591. https://doi.org/10.1016/j.cscm.2021.e00591

Akhtar, M. N., Al-Shamrani, A. M., Jameel, M., Khan, N. A., Ibrahim, Z., & Akhtar, J. N. (2021b). Stability and permeability characteristics of porous asphalt pavement: An experimental case study. *Case Studies in Construction Materials*, *15*, e00591. https://doi.org/10.1016/J.CSCM.2021.E00591

Anomin. (2013). *Cellulose fiber - Wikipedia*. https://en.wikipedia.org/wiki/Cellulose_fiber.

Cao, R., Zhao, Y., Gao, Y., Huang, X., & Zhang, L. (2019). Effects of flow rates and layer thicknesses for aggregate conveying process on the prediction accuracy of aggregate gradation by image segmentation based on machine vision. *Construction and Building Materials*, *222*, 566–578. https://doi.org/10.1016/j.conbuildmat.2019.06.147

Chen, J.-S., & Yang, C. H. (2020). Porous asphalt concrete: A review of design, construction, performance and maintenance. *International Journal of Pavement Research and Technology*, *13*(6), 601–612. https://doi.org/10.1007/s42947-020-0039-7

Chin, S. C., Tee, K. F., Tong, F. S., Ong, H. R., & Gimbun, J. (2020). Thermal and mechanical properties of bamboo fiber reinforced composites. *Materials Today Communications*, *23*(December 2019), 100876. https://doi.org/10.1016/j.mtcomm.2019.100876

Chu, L., & Fwa, T. F. (2019). Functional sustainability of single- and double-layer porous asphalt pavements. *Construction and Building Materials*, *197*, 436–443. https://doi.org/10.1016/j.conbuildmat.2018.11.162

Cui, P., Wu, S., Xiao, Y., Niu, Y., Yuan, G., & Lin, J. (2019). 3D reconstruction of moisture damage resulted volumetric changes in porous asphalt mixture. *Construction and Building Materials*, *228*, 116658.

https://doi.org/10.1016/j.conbuildmat.2019.08.039

Daly. (2017). *Asphalt Additives and Modifiers | Relationship Between Chemical Makeup of Binders and Engineering Performance | The National Academies Press*. https://www.nap.edu/read/24850/chapter/7

Dan, H. C., Wang, Z., Cao, W., & Liu, J. (2021). Fatigue characterization of porous asphalt mixture complicated with moisture damage. *Construction and Building Materials*, *303*(August), 124525. https://doi.org/10.1016/j.conbuildmat.2021.124525

Davoodi, A., Aboutalebi, M., Bayat, M., Mohammadyan-yasouj, E., & Rahman, A. (2022). Influence of nano-silica modified rubber mortar and EVA modified porous asphalt on the performance improvement of modified semi-flexible pavement. *Construction and Building Materials*, *337*(May), 127573. https://doi.org/10.1016/j.conbuildmat.2022.127573

Ding, Z., Zhang, J., Li, P., Yue, X., & Bing, H. (2019). Analysis of viscous flow properties of styrene–butadiene–styrene-modified asphalt. *Construction and Building Materials*, *229*. https://doi.org/10.1016/j.conbuildmat.2019.116881

Dong, Q., Wu, H., Huang, B., Shu, X., & Wang, K. (2013). Investigation into Laboratory Abrasion Test Methods for Pervious Concrete. *Journal of Materials in Civil Engineering*, *25*(7), 886–892. https://doi.org/10.1061/(asce)mt.1943-5533.0000683

Dr. Zainab Ahmed Al-Kaissi, O. G. M. (2016). *(PDF) Durability of Porous Asphalt Pavement*. Journal of Engineering and Sustainable Development. https://www.researchgate.net/publication/329220670_Durability_of_Porous_Asphalt_Pavement.

Fhwa. (2015). *Tech Brief: Porous Asphalt Pavements with Stone Reservoirs*.

Gao, L., Wang, Z., Xie, J., Wang, Z., & Li, H. (2020). Study on the sound absorption coefficient model for porous asphalt pavements based on a CT scanning technique. *Construction and Building Materials*, *230*, 117019. https://doi.org/10.1016/j.conbuildmat.2019.117019

Gao, Y., Gu, F., & Zhao, Y. (2013). Thermal oxidative aging characterization of SBS modified asphalt. *Journal Wuhan University of Technology, Materials Science Edition*, *28*(1), 88–91. https://doi.org/10.1007/s11595-013-0646-0

Gupta, A., Rodriguez-Hernandez, J., & Castro-Fresno, D. (2019). Incorporation of additives and fibers in porous asphalt mixtures: A review. *Materials*, *12*(19). https://doi.org/10.3390/ma12193156

Hamzah, M. O. (2004). *(PDF) Binder drainage test for porous mixtures made by varying the maximum aggregate sizes*. Rechargegate. https://www.researchgate.net/publication/228763695_Binder_drainage_test_for_porous_mixtures_made_by_varying_the_maximum_aggregate_sizes

Han, B., Yu, X., & Ou, J. (2014). Compositions of Self-Sensing Concrete. In *Self-Sensing Concrete in Smart Structures* (pp. 13–43). Elsevier. https://doi.org/10.1016/b978-0-12-800517-0.00002-2

Huang, J., Pei, J., Li, Y., Yang, H., Li, R., Zhang, J., & Wen, Y. (2020). Investigation on aggregate particles migration characteristics of porous asphalt concrete (PAC) during vibration compaction process. *Construction and Building Materials*, *243*, 118153. https://doi.org/10.1016/j.conbuildmat.2020.118153

Huang, W., Yu, H., Lin, Y., Zheng, Y., Ding, Q., Tong, B., & Wang, T. (2022). Energy analysis for evaluating durability of porous asphalt mixture. *Construction and Building Materials*, *326*(February), 126819. https://doi.org/10.1016/j.conbuildmat.2022.126819

Imadi, S. R., Mahmood, I., & Kazi, A. G. (2014). Bamboo fiber processing, properties, and applications. In *Biomass and Bioenergy: Processing and Properties* (Vol. 9783319076, pp. 27–46). Springer International Publishing. https://doi.org/10.1007/978-3-319-07641-6_2

Jiang, Z., Hu, C., Easa, S., Zheng, X., & El Halim, A. O. A. (2018). Identifying optimal polymer type of modified asphalt based on damping characteristics. *Construction and Building Materials*, *173*, 308–316. https://doi.org/10.1016/j.conbuildmat.2018.03.278

Jie, J., Zhe, W., Ran, Z., Jianming, W., Zhi, S., Zhanping, Y., & Junpeng, H. (2020). Rutting resistance of direct coal liquefaction residue (DCLR) modified asphalt mixture under variable loads over a wide temperature range. *Construction and Building Materials*, *257*, 119489. https://doi.org/10.1016/j.conbuildmat.2020.119489

JKR, SPJ, 2008. (2008). No Titleدراسة غاز الرادون في المنازل. In *standard specification for road works malaysia* (Vol. S4, pp. 1–187).

Kim1, W., Loken2, M., Chadbourn2, B., & Labuz1, and J. (n.d.). *Uniformity of Deformation in Element Testing*. Retrieved March 2, 2022, from http://www.dot.state.mn.us/materials/mr/

Koohmishi, M., & Shafabakhsh, G. (2018). Drainage potential of reservoir course of porous pavement for various particle size distributions of aggregate. *Transportation Geotechnics*, *16*(March), 63–75. https://doi.org/10.1016/j.trgeo.2018.07.002

Kusumawardani, D. M., & Wong, Y. D. (2020). The influence of aggregate shape properties on aggregate packing in porous asphalt mixture (PAM). *Construction and Building Materials*, *255*, 119379. https://doi.org/10.1016/j.conbuildmat.2020.119379

Lastra-González, P., Indacoechea-Vega, I., Calzada-Pérez, M. A., & Castro-Fresno, D. (2020). Recyclability potential of induction-healable porous asphalt mixtures. *Sustainability (Switzerland)*, *12*(23), 1–11. https://doi.org/10.3390/su12239962

LD Poulikakos, R Gubler, MN Partl, M. P. (2006). *7 must have properties of asphalt concrete - CivilBlog.Org*. Epfl.Ch. https://civilblog.org/2016/02/03/7-must-have-properties-of-asphalt-concrete/

Liew, K. M., & Akbar, A. (2020). The recent progress of recycled steel fiber reinforced concrete. In *Construction and Building Materials* (Vol. 232, p. 117232). Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2019.117232

Liu, Z., Wang, X., Luo, S., Yang, X., & Li, Q. (2019). Asphalt mixture design for porous ultra-thin overlay. *Construction and Building Materials*, *217*, 251–264. https://doi.org/10.1016/j.conbuildmat.2019.05.049

Luo, Y., Zhang, K., Li, P., Yang, J., & Xie, X. (2019). Performance evaluation of stone mastic asphalt mixture with different high viscosity modified asphalt based on laboratory tests. *Construction and Building Materials*, *225*, 214–222. https://doi.org/10.1016/j.conbuildmat.2019.07.119

Masri, K. A., Arshad, A. K., & Samsudin, M. S. (2016). Mechanical properties of porous asphalt with nanosilica modified binder. *Jurnal Teknologi*, *78*(7–2), 139–146. https://doi.org/10.11113/jt.v78.9509

Masri, K. A., Awang, H., Jaya, R. P., Ali, M. I., Ramli, N. I., & Arshad, A. K. (2019). Moisture susceptibility of porous asphalt mixture with Nano silica modified asphalt binder. *IOP Conference Series: Earth and Environmental Science*, *244*(1). https://doi.org/10.1088/1755-1315/244/1/012028

Masri, K. A., Jaya, R. P., Arshad, A. K., & Mahmud, M. Z. H. (2020). Morphological and Physical Characteristic of Stone Mastic Asphalt Mixture Incorporating Nano Silica. *The Open Civil Engineering Journal*, *14*(1), 113–125. https://doi.org/10.2174/1874149502014010113

Masri, K. A., Katini, N. H., Arshad, A. K., Shahnewaz, S., & Ferdaus, R. (2022). Microstructure analysis of porous asphalt incorporating kenaf fiber in the pavement. *Materials Today: Proceedings*, *57*, 1191–1195. https://doi.org/10.1016/J.MATPR.2021.10.194

Navin Chand, & Fahim, M. (2008). Bamboo reinforced polymer composites. In *Tribology of Natural Fiber Polymer Composites* (pp. 162–179). Elsevier. https://doi.org/10.1533/9781845695057.162

Ogundipe, O. M. (2016). Marshall Stability and Flow of Lime-modified Asphalt Concrete. *Transportation Research Procedia*, *14*, 685–693. https://doi.org/10.1016/j.trpro.2016.05.333

Peters, K. E., Kacewicz, M., & Curry, D. J. (2012). An Overview of Basin and Petroleum System Modeling: Definitions and Concepts. *Basin Modeling: New Horizons in Research and Applications*, *4*, 1–16. https://doi.org/10.1306/13311426H4139

Radzi, N. A. M., Masri, K. A., Ramadhansyah, P. J., Jasni, N. E., Arshad, A. K., Ahmad, J., Mashros, N., & Yaacob, H. (2020). Stability and Resilient Modulus of

Porous Asphalt Incorporating Steel Fiber. *IOP Conference Series: Materials Science and Engineering*, *712*(1). https://doi.org/10.1088/1757-899X/712/1/012027

Rani, M., Keshu, & Shanker, U. (2022). Green nanomaterials: An overview. *Green Functionalized Nanomaterials for Environmental Applications*, 43–80. https://doi.org/10.1016/B978-0-12-823137-1.00026-9

Rasool, R. tur, Hongru, Y., Hassan, A., Wang, S., & Zhang, H. (2018). In-field aging process of high content SBS modified asphalt in porous pavement. *Polymer Degradation and Stability*, *155*, 220–229. https://doi.org/10.1016/j.polymdegradstab.2018.07.023

Ren, S., Liu, X., Xu, J., & Lin, P. (2021). Investigating the role of swelling-degradation degree of crumb rubber on CR/SBS modified porous asphalt binder and mixture. *Construction and Building Materials*, *300*, 124048. https://doi.org/10.1016/j.conbuildmat.2021.124048

Rocky, B. P., & Thompson, A. J. (2018). Production of natural bamboo fibers-3: SEM and EDX analyses of structures and properties. *AATCC Journal of Research*, *5*(6), 27–35. https://doi.org/10.14504/AJR.5.6.4

Roseen, R. M., Ballestero, T. P., Houle, J. J., Briggs, J. F., & Houle, K. M. (2012). Water Quality and Hydrologic Performance of a Porous Asphalt Pavement as a Storm-Water Treatment Strategy in a Cold Climate. *Journal of Environmental Engineering*, *138*(1), 81–89. https://doi.org/10.1061/(asce)ee.1943-7870.0000459

Salih, S., Gómez-Meijide, B., Aboufoul, M., & Garcia, A. (2018). Effect of porosity on infrared healing of fatigue damage in asphalt. *Construction and Building Materials*, *167*, 716–725. https://doi.org/10.1016/j.conbuildmat.2018.02.065

Sindhu, R., Binod, P., & Pandey, A. (2015). Microbial Poly-3-Hydroxybutyrate and Related Copolymers. In *Industrial Biorefineries & White Biotechnology* (pp. 575–605). Elsevier. https://doi.org/10.1016/B978-0-444-63453-5.00019-7

Slebi-Acevedo, C. J., Lastra-González, P., Indacoechea-Vega, I., & Castro-Fresno, D. (2020). Laboratory assessment of porous asphalt mixtures reinforced with synthetic fibers. *Construction and Building Materials*, *234*, 117224. https://doi.org/10.1016/j.conbuildmat.2019.117224

Stammers, M., Ivanova, I. M., Niewczas, I. S., Segonds-Pichon, A., Streeter, M., Spiegel, D. A., & Clark, J. (2020). Age-related changes in the physical properties, crosslinking, and glycation of collagen from mouse tail tendon. *Journal of Biological Chemistry*, *295*(31), 10562–10571. https://doi.org/10.1074/jbc.RA119.011031

Sun, M., Zheng, M., Qu, G., Yuan, K., Bi, Y., & Wang, J. (2018). Performance of polyurethane modified asphalt and its mixtures. *Construction and Building Materials*, *191*, 386–397. https://doi.org/10.1016/j.conbuildmat.2018.10.025

Tang, G., Gao, L., Ji, T., & Xie, J. (2017). Study on the Resistance of Raveling for

Porous Asphalt Pavement. *DEStech Transactions on Materials Science and Engineering*, *0*(ictim). https://doi.org/10.12783/dtmse/ictim2017/9934

Tashman, L., Nam, K., Papagiannakis, T., Willoughby, K., Pierce, L., & Baker, T. (2008). Evaluation of Construction Practices That Influence the Bond Strength at the Interface between Pavement Layers. *Journal of Performance of Constructed Facilities*, *22*(3), 154–161. https://doi.org/10.1061/(asce)0887-3828(2008)22:3(154)

Wang, X., Gu, X., Dong, Q., Wu, J., & Jiang, J. (2018). Evaluation of permanent deformation of multilayer porous asphalt courses using an advanced multiply-repeated load test. *Construction and Building Materials*, *160*, 19–29. https://doi.org/10.1016/j.conbuildmat.2017.11.028

Wang, X., Gu, X., Ni, F., Deng, H., & Dong, Q. (2018). Rutting resistance of porous asphalt mixture under coupled conditions of high temperature and rainfall. *Construction and Building Materials*, *174*, 293–301. https://doi.org/10.1016/j.conbuildmat.2018.04.104

Wright, G. B., Arthur, S., Bowles, G., Bastien, N., & Unwin, D. (2011). Urban creep in Scotland: stakeholder perceptions, quantification and cost implications of permeable solutions. *Water and Environment Journal*, *25*(4), 513–521. https://doi.org/10.1111/j.1747-6593.2010.00247.x

Wu, X., Zheng, N., & Kong, F. (2020). The analysis of the factors affecting the macrotexture of bauxite clinker aggregate gradation. *Construction and Building Materials*, *244*, 118334. https://doi.org/10.1016/j.conbuildmat.2020.118334

Xie, J., Wu, S., Pang, L., Lin, J., & Zhu, Z. (2012). Influence of surface treated fly ash with coupling agent on asphalt mixture moisture damage. *Construction and Building Materials*, *30*, 340–346. https://doi.org/10.1016/j.conbuildmat.2011.11.022

Xu, B., Li, M., Liu, S., Fang, J., Ding, R., & Cao, D. (2018). Performance analysis of different type preventive maintenance materials for porous asphalt based on high viscosity modified asphalt. *Construction and Building Materials*, *191*, 320–329. https://doi.org/10.1016/j.conbuildmat.2018.10.004

Yang, B., Li, H., Zhang, H., Sun, L., Harvey, J., Tian, Y., Zhu, Y., Zhang, X., Han, D., & Liu, L. (2021). Environmental impact of solid waste filler in porous asphalt mixture. *Construction and Building Materials*, *303*(January), 124447. https://doi.org/10.1016/j.conbuildmat.2021.124447

Yang, J., & Tighe, S. (2013). A Review of Advances of Nanotechnology in Asphalt Mixtures. *Procedia - Social and Behavioral Sciences*, *96*(Cictp), 1269–1276. https://doi.org/10.1016/j.sbspro.2013.08.144

Ye, Y., Ngo, H. H., Guo, W., Chang, S. W., Nguyen, D. D., Zhang, X., Zhang, S., Luo, G., & Liu, Y. (2020). Impacts of hydraulic retention time on a continuous flow mode dual-chamber microbial fuel cell for recovering nutrients from municipal wastewater. *Science of the Total Environment*, *734*, 139220.

https://doi.org/10.1016/j.scitotenv.2020.139220

Yuan, G., Hao, P., Li, D., Pan, J., & Dong, S. (2020). Optimization design and verification of Large Stone Porous asphalt Mixes gradation using Compressible Packing Model. *Construction and Building Materials*, *230*, 116903. https://doi.org/10.1016/j.conbuildmat.2019.116903

Zaika, Y., & Djakfar, L. (2016). Gradation Band of Some Types Material for Reservoir Base of Porous Pavement. In *International Journal of Geomate* (Vol. 11). Online.

Zanoni, L., Boysen, A., Carlson, M., & Harris, J. (2019). *The Benefits of Using Porous Asphalt Pavement in Comparison with Other Forms of Pervious Pavements*.

Zhang, H., Gong, M., Gao, D., Yang, T., & Huang, Y. (2020). Comparative analysis of mechanical behavior of composite modified asphalt mixture based on PG technology. *Construction and Building Materials*, *259*, 119771. https://doi.org/10.1016/j.conbuildmat.2020.119771

Zhang, Y., Li, H., Abdelhady, A., & Yang, J. (2020). Comparative laboratory measurement of pervious concrete permeability using constant-head and falling-head permeameter methods. *Construction and Building Materials*, *263*, 120614. https://doi.org/10.1016/j.conbuildmat.2020.120614

Zhang, Z., Sha, A., Liu, X., Luan, B., Gao, J., Jiang, W., & Ma, F. (2020). State-of-the-art of porous asphalt pavement: Experience and considerations of mixture design. *Construction and Building Materials*, *262*, 119998. https://doi.org/10.1016/j.conbuildmat.2020.119998

Zhu, C., Zhang, H., Guo, H., Wu, C., & Wei, C. (2019). Effect of gradations on the final and long-term performance of asphalt emulsion cold recycled mixture. *Journal of Cleaner Production*, *217*, 95–104. https://doi.org/10.1016/j.jclepro.2019.01.264

List of Publications

Shahnewaz, S. M., Masri, K. A., & Ghani, N. A. A. A. (2021). Porous Asphalt Modification using Different Types of Additives: A Review. CONSTRUCTION, 1(1), 44-53.

Saikhon, M. I., Masri, K. A., Arshad, A. K., Rizam, M. F. M., Shahnewaz, S. M., & Ferdaus, R. (2021, July). Evaluation of Flexible Pavement Distresses due to Undesirable Commercial Vehicles Activity. In 2021 International Congress of Advanced Technology and Engineering (ICOTEN) (pp. 1-6). IEEE.

Rizam, M. F. M., Masri, K. A., Arshad, A. K., Saikhon, M. I., & Shahnewaz, S. M. (2021, July). Assessing Surface Defects of Flexible Pavement at Parking Lot due to Undesirable Commercial Activities. In 2021 International Congress of Advanced Technology and Engineering (ICOTEN) (pp. 1-6). IEEE.

Masri, K. A., Katini, N. H., Arshad, A. K., Shahnewaz, S., & Ferdaus, R. (2022). Microstructure analysis of porous asphalt incorporating kenaf fiber in the pavement. Materials Today: Proceedings, 57, 1191-1195.

Rodzi, A. M., Masri, K. A., Shahnewaz, S. M., Ferdaus, R., Arshad, A. K. Microstructure Analysis and Permanent Deformation of Porous Asphalt Incorporating Steel Fiber. (Under Review, Materials Today: Proceedings).