BORNEO JOURNAL OF SCIENCES AND TECHNOLOGY (BJoST)
VOL. : 05, ISSUE: 01 , 10-17
DOI: http://doi.org/10.35370/bjost.2023.5.1-02
e-ISSN: 2672-7439 © 2018, UTS Publisher.

University of Technology Sarawak

ORIGINAL ARTICLE

Performance of Asphalt Mixture Incorporating Oil Palm Fruit Ash as Modified Binder

*[1]Mastura Bujang, [1]Nisa 'Aqila Bakie, [1]Ummi Humaira Bujang, [1]Lee Siaw Kian, [2]Euniza Jusli and [3]Wan Nur Aifa Wan Azahar

[1] Centre for Research of Innovation and Sustainable Development, School of Engineering and Technology, University of Technology Sarawak, 96000 Sibu, Sarawak, Malaysia
[2] Faculty of Engineering & Quantity Surveying, Inti International University, 71800 Nilai, Negeri Sembilan, Malaysia
[3] Department of Civil Engineering, International Islamic University Malaysia, 53100 Selangor, Malaysia

ABSTRACT - The disposal of oil palm fruit ash (OPFA) in landfills keep increasing over the years due to the increasing numbers of palm oil plantations in Malaysia, specifically in Sarawak. This waste material might cause environmental problems and it should be used as alternative materials in pavement construction to promote 3R's (Reduce, Recycle, Reuse) concept. Hence, this study was conducted to determine the performance of asphalt mixture incorporating OPFA as binder modifier in bitumen grade 60/70 at different percentages by weight of OPFA contents (0%, 10%, 20%, 30%, and 40%). Aggregate tests and bitumen tests were conducted to evaluate the physical properties of asphalt mixture, meanwhile resilient modulus test and dynamic creep test were conducted to determine the compatibility of OPFA in asphalt mixture (AC20). Based on the laboratory tests, it showed that the modified binder was having higher resistance towards temperature and deformation compared to the control sample. The mixture with 40% OPFA yielded the highest value of resilient modulus at both temperatures, 25˚C and 40˚C with 10992 MPa and 2936 MPa respectively. For dynamic creep test, modified bitumen with 40% OPFA also achieved the lowest deformation which was 0.20 mm compared to other mixtures. In conclusion, this study indicated that OPFA actually can be used as a binder modifier to improve the performance of hot mix asphalt (HMA) which indirectly can reduce the number of waste materials disposed and save the environmental problems.

ARTICLE HISTORY
Received: 07 Jan 2022
Revised: 13 June 2022
Accepted: 09 Sept 2022

KEYWORDS
Sustainability
Waste material
Oil palm fruit ash Binder modifier
Asphalt mixture

INTRODUCTION

The demand for road construction keeps on continuously increasing with the growth of population growth, urbanization, and industrialization. Pavement is a strong surface material that is a significant channel of transportation to support the vehicular and pedestrian activity especially for carrying goods and passengers. There are about 95% of roads are made of flexible pavement which consists of 94% to 96% by weight of the aggregate and filler, while 4% to 6% of bitumen as the main materials [1],[2]. These natural pavement materials have shown a decreasing rate with the growing number of waste materials in landfills that can affect the needs of future generations [3],[4]. The criteria of sustainability in road construction can be identified by implementing the use of alternative natural pavement materials which indirectly can minimize the energy consumption, fumes emission during production, and minimize the construction cost [5],[6]. These alternatives materials are derived from various sources such as waste glasses [7],[8],[9],[10],[11], steel slag [12],[13],[14],[15],[16],[17], oil palm fruit ash [18],[19], waste plastics [20],[21], concrete construction demolition [22],[23],[24],[25],[26], recycled asphalt pavement

*Corresponding Author: Mastura Bujang. University of Technology Sarawak (UTS),
email: mastura.bujang@uts.edu.my

and shingle [27],[28],[29],[30], waste tyre rubber [31],[32], coal bottom ash [33],[34],[35], waste cooking oil [5], and basalt waste [36].

Malaysia is one of the largest palm oil producers other than Indonesia and Thailand which successfully generates almost 32% of the palm oil supply [37],[38]. There are about 5% of the oil palm fruit ash (OPFA) are produced as a solid by-product of palm oil mill during the process of burning fruitlets mesocarp and will be directly disposed to the landfills [39]. Hence, using OPFA as a natural material replacement or additive in pavement might help to reduce the environmental problems and improve the performance of the pavement. Additives have been used in asphalt binders to design against the road defects such as raveling, stripping, rutting, shoving, and cracking. This study reveals the performance of asphaltic concrete (AC20) incorporating OPFA as a binder modifier in bitumen grade 60/70 as one of the green techniques to be proposed to the road practitioners in Malaysia. This technique might be useful to help in reducing the number of waste materials in landfills and promote the 3R's (reduce, reuse, recycle) concepts in road construction.

MATERIALS AND METHODOLOGY

The laboratory tests were conducted at University of Technology Sarawak (UTS) for aggregates, bitumen, and asphalt mixtures. The aggregates with a maximum size of 20 were obtained from Lamy Industries Sdn. Bhd., while bitumen grade 60/70 and OPFA with size passing 0.075 mm were obtained from Fosxil Petroleum Sdn. Bhd. and Retus Palm Oil Mill Sibu respectively. Table 1 shows the physical and chemical properties of OPFA. Based on these properties, it shows that OPFA consists of high silica content which makes it an excellent pozzolanic material. The oven-dried OPFA was blended with natural bitumen at various percentages which are 10%, 20%, 30%, and 40% by weight, and known as a modified binder.

Table 1. Physical and chemical properties of OPFA [40]

Physical property	**Value**
Specific Gravity	2.22
Fineness – Sp. surface area (m^2/kg)	518
Chemical composition	**%**
Aluminium Oxide (Al_2O_2)	11.40
Ferric Oxide (Fe_2O_2)	4.70
Silicon Dioxide (SiO_2)	43.60
Magnesium Oxide (MgO)	4.80
Calcium Oxide (CaO)	8.40
Potassium Oxide (k_2)	3.50
Sodium Oxide (Na_2O)	0.39
Loss on Ignition (LOI)	18.00
Sulphur Trioxide (SO_3)	2.80

The aggregates and bitumen tests in this study were water absorption test, aggregate impact value (AIV) test, aggregate crushing value (ACV) test, Los Angeles abrasion value (LAAV) test, softening point test, penetration test, and specific gravity test respectively. Other than that, the resilient modulus test and dynamic creep test were conducted to determine the performance of AC20 with OPFA as a binder modifier. Figure 1 presents the framework of this study.

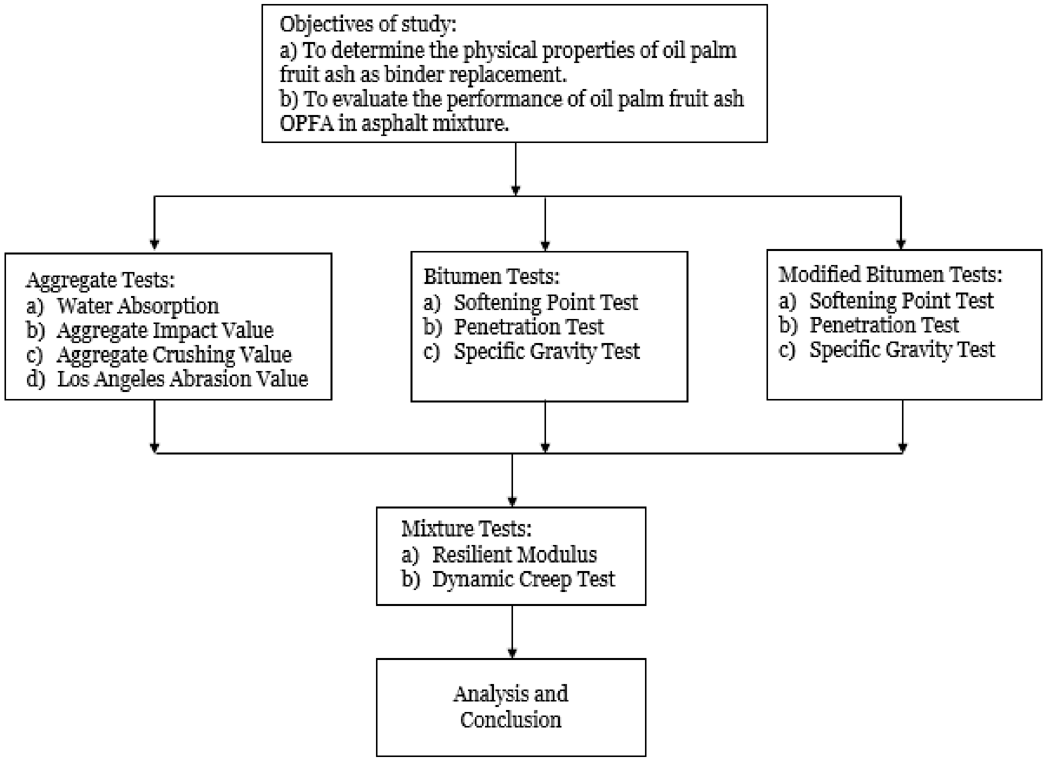

Figure 1. Research Operational Framework

RESULTS AND DISCUSSION

AGGREGATE TEST

Table 2 presents the results of aggregate tests. The average of water absorption results obtained from the test was 1.8% and the value was acceptable in accordance with Malaysian standards [41]. The aggregate should have an adequate porosity rate to ensure it can absorb the bitumen for coating and create strong bonding in the mix design. For AIV test, the average value was 13.0% which was less than 25% based on Malaysian standards and it proved that these aggregates were suitable to be used in construction as they were able to resist the disintegration due to impact from vehicles. A lower impact value of aggregates indicates high durability and toughness in its properties [41]. According to Table 2, ACV test and LAAV test results were 24.5% and 23.0% respectively which were accepted as the value was less than 25% [41]. Thus, the aggregates were suitable to be used in construction as they were able to withstand the crushing load under wheel loading and resist the abrasion force due by vehicles.

Table 2. Aggregate test

Name of Aggregate test	Average (%)	JKR standard [41] (%)
Water Absorption	1.8	< 2
Aggregate Impact Value	13.0	< 25
Aggregate Crushing Value	24.5	< 25
Los Angeles Abrasion Value	23.0	< 25

BITUMEN TEST

The bitumen test results are summarized in Table 3 and the average value of penetration test bitumen grade PEN 60/70 was 62.5 mm. The result showed that this bitumen was suitable to be used in this study as the grade of bitumen was in the range of 60 mm until 70 mm penetration. This test was conducted to measure the consistency of bitumen's property, whether it is hard or soft. Other than that, the result obtained for softening point test was 48˚C which was acceptable to be used as it was within the standard specification. For the specific gravity test, the result was 1.04 which was satisfied the standard specification and suitable to be used as a binder in pavement mixture.

Table 3. Bitumen test

Name of Bitumen test	Average	Specification	Reference
Penetration	62.5 mm	60 – 70 mm	ASTM D0005-13
Softening Point	48˚C	48 - 56˚C	ASTM D0036-95
Specific Gravity	1.04	1.00 – 1.06	ASTM D0070-09

MODIFIED BITUMEN TEST

Table 4 shows the average results of modified bitumen tests based on different percentages of OPFA contents; 10%, 20%, 30%, and 40%. Based on findings, penetration test for 10% of OPFA yielded the highest value compared to the other percentages which was 61.2 mm. Other than that, 40% of OPFA achieved the highest value of temperature and specific gravity compared to other percentages for the softening point test and specific gravity test; 50.5°C and 1.25 respectively. These results showed that the increasing amount of OPFA content in bitumen 60/70 might increase the hardness of the binder mixture and increase the allowable temperature at which bitumen can withstand that suit Malaysian weather conditions. It also revealed that the fineness of OPFA also affects the characteristic of bitumen in the mixture.

Table 4. Modified bitumen test containing OPFA

Name of Bitumen test	10% OPFA	20% OPFA	30% OPFA	40% OPFA
Penetration	61.2 mm	56.1 mm	46.1 mm	46.1 mm
Softening Point	48.0˚C	49.5˚C	50.0˚C	50.5˚C
Specific Gravity	1.06	1.19	1.21	1.25

RESILIENT MODULUS TEST

The resilient modulus test is a measure of pavement response in terms of dynamic stresses-strains and estimation of modulus of elasticity especially when the pavement is applied to repeated loading. Besides that, the structural behaviour of the pavement against traffic loading can be determined at two different temperatures, 25˚C and 40˚C. Figure 2 shows the resilient modulus test results at 25˚C and 40˚C for the control and four different percentages of OPFA contents samples. The results obtained show that the 40% of OPFA modified binder achieved a higher value of modulus which were 10992 MPa and 2936 MPa at 25˚C and 40˚C respectively. This is due to the content of OPFA with high silica concentration that might have some pozzolanic cementing nature which provides strong binding agents for making the mixture bonding stronger. Apart from that, low penetration value and high softening point value cause OPFA significantly improved the mechanical properties and resistance to moisture damage of asphalt mixture [42]. These results indicate that a higher percentage of the modified binder contained with OPFA in asphalt mixture can improve its stiffness, and subsequently give higher load-bearing capacity and cracking resistance to the pavement [43].

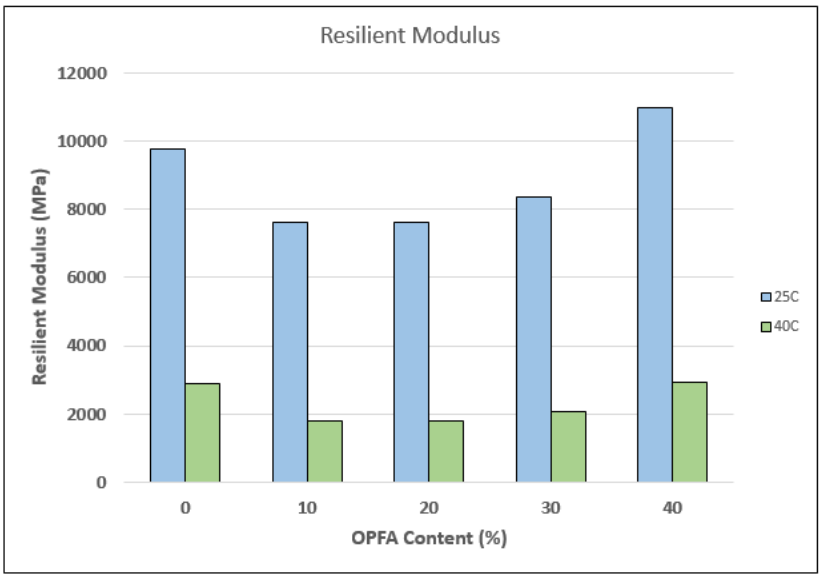

Figure 2. Resilient Modulus at 25˚C and 40˚C

DYNAMIC CREEP TEST

The dynamic creep test is a test that applies a repeated pulsed uniaxial stress on an asphalt specimen and measures the resulting deformations in the same direction using linear variable differential transducers (LVDTs). Other than that, this test aims to study the response relationship between pavement load and deformation to evaluate the rutting resistance of asphalt pavements at the temperature 40˚C. Based on Figure 3, the control sample obtained 0.91 mm of deformation value, meanwhile 40% of OPFA modified binder yielded the lowest deformation value which was 0.20 mm. This is might be due to the fineness of OPFA helping in reducing the voids in the asphalt mixture, indirectly improving the bonding in the mixture, increasing its stiffness and the resistance toward the permanent deformation at high temperature.

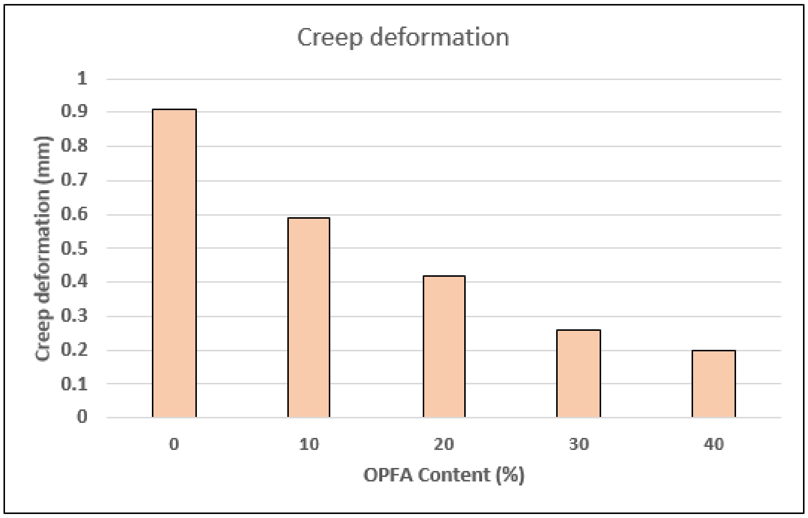

Figure 3. Creep deformation at 40˚C

CONCLUSIONS

Based on the limited tests conducted in this study, the following conclusions were derived:

• By adding OPFA to the bitumen 60/70, it has increased the hardness of the binder mixture, softening point temperature, and specific gravity value compared to the control sample.
• According to the resilient modulus and dynamic creep test, the findings show that 40% of OPFA added to bitumen 60/70 has improved the performance of the asphalt mixture (AC20) in terms of its elasticity modulus, stiffness, and deformation compared to AC20 mixed with the conventional bitumen.
• Generally, the presence of OPFA as a binder modifier enhances the binder adhesion with the aggregates in AC20 without impairing the performance properties of mixtures. This is due to its physical and chemical properties that enable OPFA to perform as a pozzolanic material that improved the rheological behaviour of asphalt mixture by increasing its stiffness, strength, and rutting resistance at tropical temperatures.

ACKNOWLEDGEMENT

The authors would like to extend their gratitude to the University of Technology Sarawak Research grant (UCTS/RESEARCH/4/2018/03) for the financial support in this research project.

REFERENCES

[1] Huang, Y., Bird. R.N. and Heidrich, O. 2007. A Review of the Use of Recycled Solid Waste Materials in Asphalt Pavements. Resour. Conserv. Recyl. 52 (2007) 58-73.
[2] Babalghaith, A.M., Koting, S., Sulong, N.H.R., Karim, M.R., and Almashjary, B.M. 2020. Performance Evaluation of Stone Mastic Asphalt (SMA) Mixtures with Palm Oil Clinker (POC) as Fine Aggregate Replacement. Construction and Building Materials, 262(2020). 120546.
[3] Idham, M. K. and Hainin, M. R. 2015. The Effect of Incorporating Reclaimed Asphalt Pavement on the Performance of Hot Mix Asphalt Mixtures. Jurnal Teknologi. 77 (32), 117–123.
[4] Azahar, W. N. A. W, Bujang, M., Jaya, R. P., Hainin, M. R., Ngadi, N. and & Abdullah, M. M. A. B. 2016. Performance of Waste Cooking Oil in Asphalt Binder Modification. Key Engineering Materials. 700, 207-215.
[5] F. Autelitano, E. Garilli, F. Giuliani. 2017. Road route planning for transporting wind turbines in Europe. Transp. Infrastruct. Syst., CRC Press. 2017, 301–308.

[6] Bolden, J., Abu-Lebdeh, T. and Fini, E. 2013. Utilization of recycled and waste materials in various construction applications, Am. J. Environ. Sci. 9 (1) (2013) 14–24.
[7] Su, N. and Chen, J. 2002. Engineering properties of asphalt concrete made with recycled glass, Resour. Conserv. Recycl. 35 (4) (2002) 259–274.
[8] Shafabakhsh, G.H. and Sajed, Y. 2014. Investigation of dynamic behavior of hot mix asphalt containing waste materials; case study: glass cullet, Case Stud. Constr. Mater. 1 (2014) 96–103.
[9] Arabani, M. and Pedram, M. 2016. Laboratory investigation of rutting and fatigue in glassphalt containing waste plastic bottles, Constr. Build. Mater. 116 (2016) 378–383.
[10] Androjic´, I. and Dimter, S. 2016. Properties of hot mix asphalt with substituted waste glass, Mater. Struct. 49 (1–2) (2016) 249–259.
[11] Zakaria, N.M., Hassan, M.K., Ibrahim, A.N.H., Rosyidi, S.A.P., Yusoff, N.I.M., Mohamed, A.A. and Hassan, N. 2017. The use of mixed waste recycled plastic and glass as an aggregate replacement in asphalt mixtures, Jurnal Teknologi 80 (1) (2017) 79–88.
[12] Pasetto, M. and Baldo, N. 2011. Mix design and performance analysis of asphalt concretes with electric arc furnace slag, Constr. Build. Mater. 25 (8). 3458–3468.
[13] Ameri, M. and Behnood, A. 2012. Laboratory studies to investigate the properties of CIR mixes containing steel slag as a substitute for virgin aggregates, Constr. Build. Mater. 26 (1). 475–480.
[14] Wu, S., Xue, Y., Ye, Q. and Chen, Y. 2007. Utilization of steel slag as aggregates for stone mastic asphalt (SMA) mixtures, Build. Environ. 42 (7). 2580–2585.
[15] Chen, Z., Wu, S., Xiao, Y., Zhao, M. and Xie, J. 2016. Feasibility study of BOF slag containing honeycomb particles in asphalt mixture, Constr. Build. Mater. 124 (2016) 550–557.
[16] Chen, Z., Wu, S., Wen, J., Zhao, M., Yi, M. and Wan, J. 2015. Utilization of gneiss coarse aggregate and steel slag fine aggregate in asphalt mixture, Constr. Build. Mater. 93 (2015) 911–918.
[17] Behnood, A. and Ameri, M. 2012. Experimental investigation of stone matrix asphalt mixtures containing steel slag, Scientia Iranica 19 (5). 1214–1219.
[18] Ndoke, P.N. 2006. Performance of palm kernel shells as a partial replacement for coarse aggregate in asphalt concrete, Leonardo Electron. J. Pract. Technol. 5 (9). 145–152.
[19] Oyedepo, O.J., Olanitori, L.M. and Olukanni, E.O. 2015. Investigation of palm kernel shell as partial replacement for aggregate in asphaltic concrete, Malaysian J. Civil Eng. 27 (2). 223–234.
[20] Rahman, W.M.N.W.A. and Wahab, A.F.A. 2013. Green pavement using recycled polyethylene terephthalate (PET) as partial fine aggregate replacement in modified asphalt, Procedia Eng. 53 (2013) 124–128.
[21] Modarres, A. and Hamedi, H. 2014. Effect of waste plastic bottles on the stiffness and fatigue properties of modified asphalt mixes, Mater. Des. 61 (2014) 8–15.
[22] Pourtahmasb, M.S. and Karim, M.R. 2014. Performance evaluation of stone mastic asphalt and hot mix asphalt mixtures containing recycled concrete aggregate, Adv. Mater. Sci. Eng. 2014.
[23] Ossa, A., García, J. and Botero, E. 2016. Use of recycled construction and demolition waste (CDW) aggregates: a sustainable alternative for the pavement construction industry, J. Cleaner Prod. 135 (2016) 379–386.
[24] Fatemi, S. and Imaninasab, R. 2016. Performance evaluation of recycled asphalt mixtures by construction and demolition waste materials, Constr. Build. Mater. 120 (2016) 450–456.
[25] Gómez-Meijide, B., Pérez, I., Airey, G. and Thom, N. 2015. Stiffness of cold asphalt mixtures with recycled aggregates from construction and demolition waste, Constr. Build. Mater. 77 (2015) 168–178.
[26] Nwakaire, C.M., Yap, S.P., Yuen, C.W., Onn. C.C., Koting, S. and Babalghaith, A.M. 2020. Laboratory study on recycled concrete aggregate based asphalt mixtures for sustainable flexible pavement surfacing, J. Cleaner Prod. 262 (2020) 121462.
[27] Tapsoba, N., Baaj, H., Sauzéat, C., Di Benedetto, H. and Ech, M. 2016. 3D analysis and modelling of thermal stress restrained specimen test (TSRST) on asphalt mixes with RAP and roofing shingles, Constr. Build. Mater. 120 (2016) 393–402.
[28] Colbert, B., Hasan, M.R.M. and You, Z. 2016. A hybrid strategy in selecting diverse combinations of innovative sustainable materials for asphalt pavements, J. Traffic Transp. Eng. (English Ed.) 3 (2) (2016) 89–103.
[29] Abreu, L.P., Oliveira, J.R., Silva, H.M. and Fonseca P.V. 2015. Recycled asphalt mixtures produced with high percentage of different waste materials, Constr. Build. Mater. 84 (2015) 230–238.
[30] Falchetto, A.C., Montepara, A., Tebaldi, G. and Marasteanu, M.O. 2012. Microstructural and rheological investigation of asphalt mixtures containing recycled asphalt materials, Constr. Build. Mater. 35 (2012) 321–329.
[31] Mashaan, N. 2016. Use of waste tyre rubber in enhancing the mechanical properties of stone mastic asphalt mix, Doctor of Philosophy, Civil Engineering, University of Malaya, Malaysia, 2016.
[32] Selim, A.A., Muniandy, R. and Abdelrahman, M. 2005. Potential use of ground tire rubber in stone matrix asphalt (SMA)-A laboratory evaluation, in: 2005 International Symposium on Pavement Recycling, 2005.
[33] Colonna, P., Berloco, N., Ranieri, V. and Shuler, S. 2012. Application of bottom ash for pavement binder course, Procedia-Social Behav. Sci. 53 (2012) 961–971.

[34] Pandey, Y. and Tare, V. 2016. Utilization of coal mixed waste aggregates available atthermal power plants for GSB and asphalt mixtures, Procedia Eng. 143 (2016) 170–177.
[35] Yoo, B.-S., Park, D.-W. and Vo, H.V. 2016. Evaluation of asphalt mixture containing coal ash, Transp. Res. Procedia 14 (2016) 797–803.
[36] Karakus_A. 2011. Investigating on possible use of Diyarbakir basalt waste in Stone Mastic Asphalt, Constr. Build. Mater. 25 (8) (2011) 3502–3507.
[37] Abdullah, R. & Wahid, M. B. 2010. World palm oil supply, demand, price and prospects, Malaysian: Malaysian palm oil board.
[38] Lam, M.K., Jamalluddin, N.A., and Lee, K.T. 2019. Chapter 23 - Production of biodiesel using palm oil, in: A. Pandey, C. Larroche, C.-G. Dussap, E. Gnansounou, S.K. Khanal, S. Ricke (Eds.), Biofuels: Alternative Feedstocks and Conversion Processes for the Production of Liquid and Gaseous Biofuels, 2nd ed., Academic Press, pp. 539–574.
[39] Coelho, V., Guimaraes, C., Doutto, G. & Pedra, P. 2019. Evaluation of mortar properties obtained through partial substitution of Portland cement by ashes of oil palm empty fruit bunch. Cerâmica , pp. 359-369.
[40] Rusbintardjo, G., Hainin, M.R., Mubaraki, M.A., and Yusoff, N.I.M. 2014. The Performance Characteristics of Stone Mastic Asphalt Mixtures using Oil Palm Fruit Ash-Modified Bitumen. International Journal of Pavemen Research and Technology, 7(4). 227-236.
[41] Jabatan Kerja Raya , JKR. 2008. Standard specification for road works. Malaysia
[42] Al-Sabaeei, A.M., Al-Fakih, A., Noura, S., Yaghoubi, E., Alaloul, W., Al-Mansob, R.A., Khan, M.I. and Yaro, N.S.A. 2022. Utilization of palm oil and its by-products in bio-asphalt and bio-concrete mixtures: A review. Construction and Building Materials 337 (2022). 127552.
[43] Borhan, M.N., Ismail, A. and Rahmat, R.A. 2010. Evaluation of Palm Oil Fruit Ash (POFA) on Asphalt Mixtures. Australian Journal of Basic and Applied Science, C(). CC-CC.