PAPER • OPEN ACCESS

A review on nanomaterials as additive in asphalt binder

To cite this article: K A Masri *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **682** 012055

A review on nanomaterials as additive in asphalt binder

K A Masri[1,2*], S M Z Nur Syafiqah[1], M A Seman[1], P J Ramadhansyah[1], H Yaacob[3] and N Mashros[3]

[1]Department of Civil Engineering, College of Engineering, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300, Gambang, Kuantan, Pahang, Malaysia
[2]Earth Resources and Sustainability Centre (ERAS), Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia
[3]Faculty of Engineering, School of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia

Corresponding author: khairilazman@ump.edu.my

Abstract. Nowadays pavement tends to experience extra loadings and deteriorates faster than expected. There are various ways that has been done in order to withstand permanent deterioration such as adding fibers, polymers and waste materials. Some shows a good enhancement in the terms of fatigue life and dynamic creep. Nanotechnology is being expanded in the highway area thus, nanomaterials such as nano silica, nano clay, iron oxide nanoparticles and others are being incorporated in asphalt as modifier or additives. Some of the nanomaterials improves the mechanical performance of asphalt mixture and increase fatigue life. This review paper discusses the advantages of using nanomaterials in asphalt as an additive

1. Nanotechnology in asphalt

Asphalt pavements are considered the best method to pave highways due to its features such as reduced noise, good skid resistance, the opportuneness of maintenance, recyclability, high stability, high durability, good resistance against water damage, and improved comfort [1]. The permanent deformation and cracking in asphalt pavement are highly related to high and low service temperatures since the bitumen is a substance sensitive to aging, and its properties deteriorate over the service life. The use of modifiers such as polymers and fibres in bitumen in asphalt samples is a common method to improve the behaviour of asphalt mixtures, while the researchers used the nano materials to improve the behaviour of bitumen and asphalt mixtures in recent years [2]. Nanomaterials is a part of nanotechnology which has become an area of interest among researchers. Nanotechnology is the development of new materials, devices and systems at molecular level, a phenomenon associated with atomic and molecular interactions, which greatly affects the macroscopic properties of materials [3], [4]. Although nanotechnology is widely used in science, it is yet to be explored in the pavement industry. Therefore, more study is done in order to access the advantages nanotechnology offered in terms of nanomaterials in asphalt mixtures

2. Nanomaterials as additive

Various materials like fiber, reclaimed asphalt pavement (RAP), crumb rubbers and polymers have been utilized in the asphalt pavement. RAP and crumb rubber are famous in producing an environmentally friendly asphalt mix due to reduce emission of carbon dioxide. However, because of its high replacement percentage in the mixture it arises concern. Polymers also have it drawbacks in terms of high cost, low ageing resistance and poor storage stability of polymer modified bitumen. In view of this, nanomaterial emerge as a new option for the research in asphalt mixtures. In recent years, nanomaterials have been broadly employed in the area of asphalt pavement as a result of their unique characteristics including large planar surface area and small size between 1 and 100 nm, and potential to yield novel asphalt materials that are able to increase the durability and service life of flexible pavements [5]. Many studies have been conducted on using nano material in different areas, but about using these materials in pavement industry, only the use of few nanomaterials to improve the asphalt concrete properties can be mentioned [6]. Recently, application of nano additives in asphalt binder has been developed rapidly, since they have unique properties such as quantum effects, structural features and high surface area [7]. Some of the nanomaterials that are widely used are nano clay, nano silica and nano titanium. The following section addressed the application of nanomaterials to binder modification in terms of their properties and efficiency

3. Nano clay

Nano clays are nanoparticles of layered mineral silicates. Depending on chemical composition and nanoparticle morphology, nano clays are organized into several classes such as montmorillonite, bentonite, kaolinite, hectorite, and halloysite. The most common usage of nano clay type is montmorillonite with its platy like structure. Montmorillonite consists of ~ 1 nm thick aluminosilicate layers surface-substituted with metal cations and stacked in ~ 10 µm-sized multilayer stacks. Depending on surface modification of the clay layers, montmorillonite can be dispersed in a polymer matrix to form polymer-clay nanocomposite. Moreover, fatigue life is improved when nano clay is incorporated and minimize rutting failure. Nano clay possess high length over width ratio. There exists a mixed trend of moisture damage resistivity of nano clay modified binders but there are a few exposures on the issue.

3.1. Application of nano clay

The effects of the modifications with nano clays were dependent of the type of nano clay (Figure 1). Besides the particle size distribution (Table 1) and the specific surface area (Figure 2), the type of treatment, raw (hydrophilic) or organically modified (hydrophobic), can have particular importance in the obtained effects. Generally, the effects of nano clays modifications are higher Marshall stability, lower permanent deformation, higher stiffness modulus at high temperatures, better fatigue resistance, and higher resistance to moisture damage. The studies found in literature covered the dosage range of 1% to 7% and, the effects of the modifications increase according with the increase in dosage. Nevertheless, in the case of some organically modified nano clays, the performance enhancement peaked at relatively low dosages (e.g. 2%) and a further increase in dosage worsened the performance. As the cost of organically modified nano clays can be roughly double the cost of raw nano clay, the use of such modifications should be careful optimized to ensure maximum performance with lowest dosage possible [8].

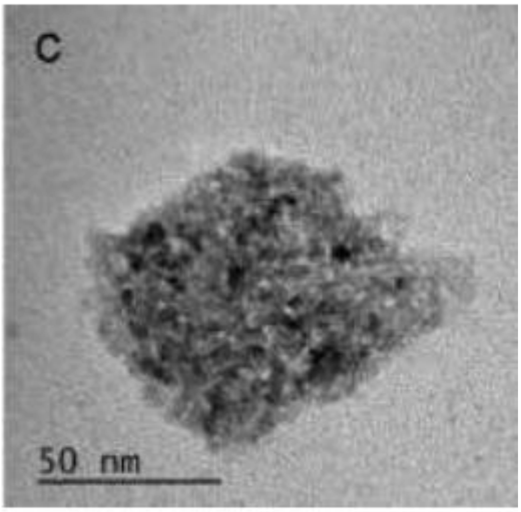

Figure 1. TEM image for nano clay [9].

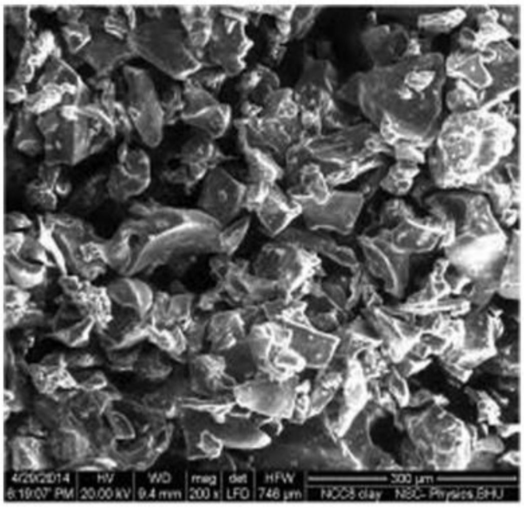

Figure 2. SEM image of nano clay at 3000 x magnification [10].

Table 1. Properties of the nano clay [11]

Particle size	Color	Density	Moisture content	Specific surface area
1-2nm	Pale yellow	0.5-0.7 g/cm^3	1-2%	220-270 m^2/g

4. Nano silica

In general, nano silica was produced from micro based silica as tabulated in Table 2. Silica is a naturally occurring form of silicon dioxide [12], SiO_2 such as quartz sand, rocks and clay, and is widely used in the manufacture of silica gels, colloidal silica and fumed silica in industry, Nano silica (NS), derived from processed silica, has a maximum dimension of about 30 nm. It is an inorganic material that possesses beneficial properties such as large surface area, good dispersal ability, strong adsorption, high chemical clarity and excellent stability. NS has been widely used in polymer, concrete and asphalt binder as inorganic filler to improve the properties of polymeric, mechanical and bituminous materials [13].

Table 2. Properties of Nano silica [14],[15],[16]

Properties	Value
Appearance	Slightly milky transparent
SiO_2 (%)	30%
Na_2O (%)	0.5%
pH	8.5 - 10.5
Density	1.19 - 1.22 g/cm^3
Particle size	10-15 nm

4.1. Application of nano silica

Previous study on nano silica was performed to improve the mechanical performance of asphalt mixtures. Taherkhani and Afroozi [17] in their research concludes that with increasing nano silica content, the stiffness of asphalt increased and its temperature sensitivity decreased indicating that the nano-silica modification improved the resistance against permanent deformation and low temperature cracking of asphalt cement [16, 22, 23]. The study was done to investigate the performance of the nano-silica modified asphaltic concrete, focusing on the modelling of creep behaviour under dynamic loading. In order to investigate the stress dependency of the creep behaviour of the mixtures, the tests were conducted on the control mixture and the mixtures containing 1, 3 and 5% of nano-silica content at 50°C and stress levels of 200 and 400 kPa. In addition, to investigate the temperature sensitivity, the dynamic creep tests were conducted on the control mixture and the mixture containing the optimum nano-silica content at 40 and 60°C and stress level of 200 kPa. It can be seen that, over the range of nano-silica contents used in this research, the optimum nano-silica content for achieving the highest resistance against permanent deformation is 5% (Figure 3 to Figure 5). Therefore, in order to investigate the effects of temperature on the resistance against permanent deformation, the dynamic creep test was conducted on the mixture containing 5% of nano-silica at 40 and 60°C and subjected to 200 kPa, and compared with the control mixture. Another one is by adding 4% of nano silica, it is also proven that the mechanical performance of SMA20 and AC14 is improved as shown in a research by Arshad et al [16] conducted in 2017, the mechanical performance is evaluated by terms of mix design, resilient modulus, rutting resistance and moisture susceptibility.

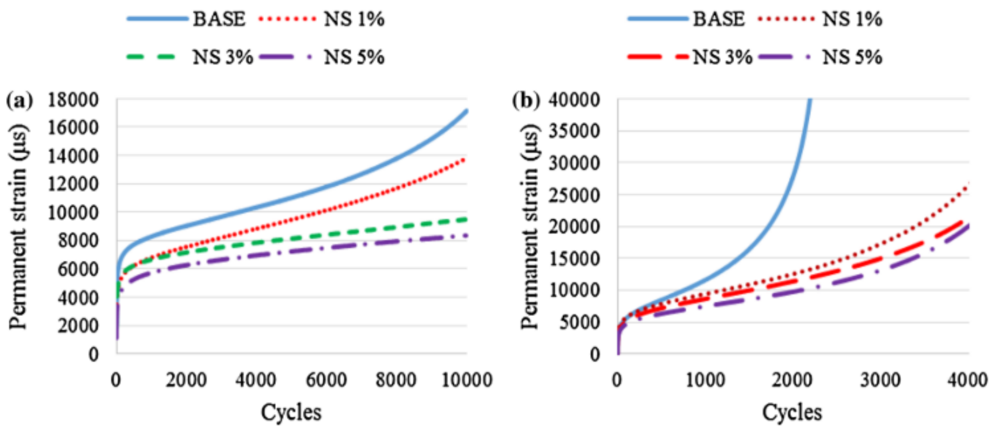

Figure 3. Creep curves of the mixtures subjected to (a) 200 kPa and (b) 400 kPa at 50°C [17]

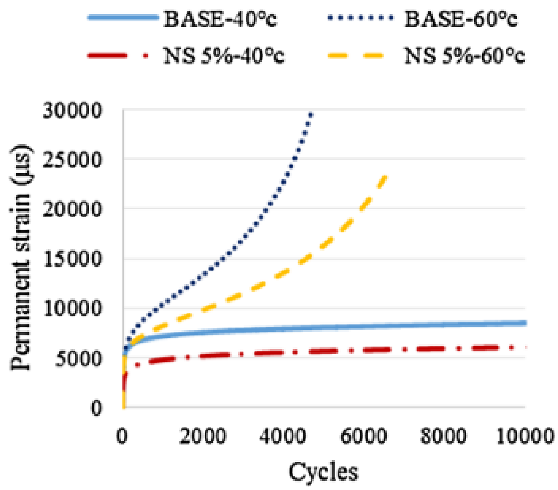

Figure 4. Creep curves of the control mixture and the mixture containing 5% of nano-silica subjected to 200 kPa at 40 and 60°C [17]

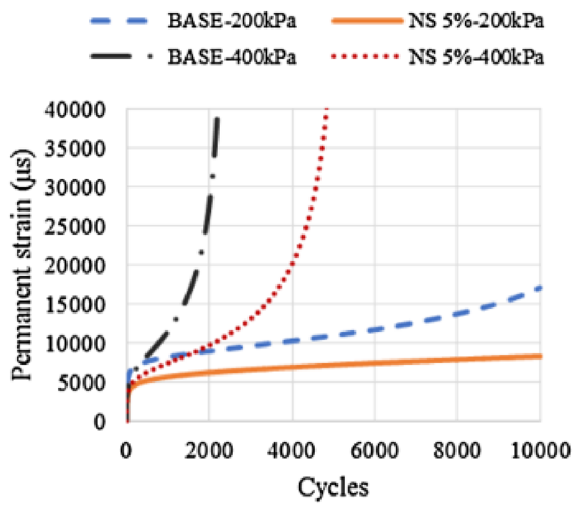

Figure 5. Creep curves of the control mixture and the mixture containing 5% of nano-silica subjected to 200 kPa and 400 kPa at 50°C [17]

Sezavar et.al [18] conducted a study to observe the effect of nano silica on moisture susceptibility. It showed that the modified nano silica asphalt specimen has a higher rate of tensile strength, indirect tensile strength and more compressive than the conventional asphalt specimen. The effect of nano-silica on specimens with binder 85–100 is less than the specimens with 60–70 binder and has higher moisture susceptibility [18].

5. Graphene and graphene oxide (GO)

Graphene and Graphene Oxide (GO) are regarded as two of the most promising materials because of their surface area size along with exceptional electrical and physical properties [19]. The addition of GO at 0.05% by weight of asphalt binder can enhance the aging resistance of asphalt mixture, reduce the moisture susceptibility of the aged mixtures, and weaken the influence of aging on its low-temperature performance [20]. The addition of GO to asphalt increases the softening point, viscosity and residual penetration ratio, especially the residual penetration ratio, but a decrease is shown on the values of ductility and penetration. GO improves the high temperature stability and heat aging resistance of asphalt, but does not improve the crack resistance of asphalt [21].

5.1. Application of graphene oxide

Mukhtar et al [5] has conducted a study on hot mix asphalt by incorporating graphene oxide (GO) as the asphalt binder as illustrated in Figure 6. From it, compared to the conventional asphalt mix the modified mix shows a significant resistance to cracking damage and rutting resistance. Based on Figure 7, the modified mixture has higher resilient modulus value at 25°C compared to 40°C with 2% GO. It can be seen that GO is more significant at 25°C rather than high temperature of 40°C. Not only that, GO is shown to enhance moisture susceptibility at addition of 1 and 1.5% of GO in to the mix while not the same could be said for the 2% addition as it shows the least moisture susceptibility. In the basis of current literature, the use of GO as an additive to the modification of the asphalt binder is still quite recent and needs to be extensively investigated. There is also a lack of work on the efficiency of asphalt mixture modified with GO.

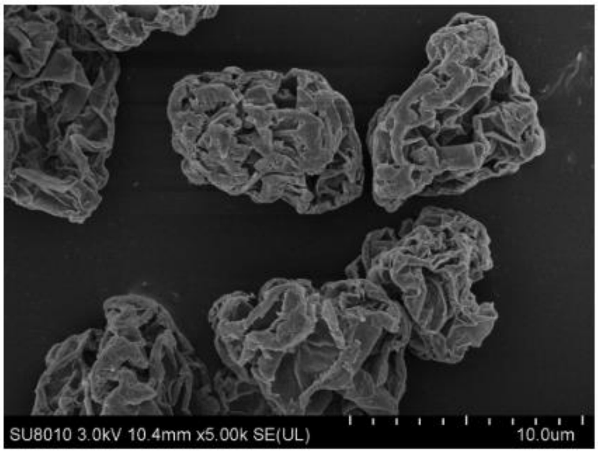

Figure 6. : SEM image of GO [5]

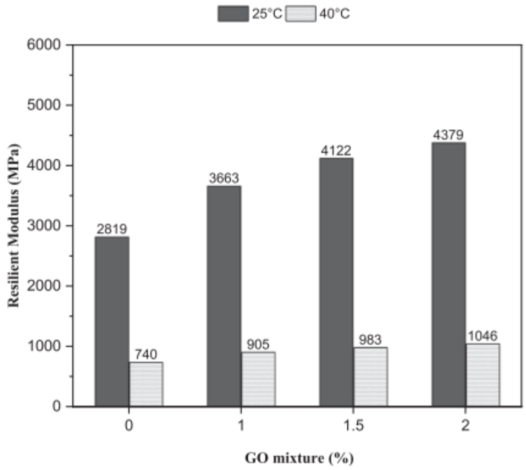

Figure 7. Resilient modulus test results [5]

6. Conclusion

This review discusses the application of nanomaterials in asphalt pavements. Some of the nanomaterials used are enhancing the mechanical performance of the asphalt but there is still some missing component in the aspect of the nanomaterial used. From this, some of the advantages of including nanomaterials in asphalt mix are:

a) Prolong the fatigue life of asphalt mixture making it last longer.
b) At higher temperature, more resistance is shown to the loading stresses inflicted.
c) A potential improvement on moisture damage depending on the type or composition of nanomaterials used.

More research needs to be done in order to access the nanomaterials in the asphalt pavement, given different characteristics of the nanomaterials could also influence the effect it has on the asphalt mixture

7. References

[1] D. Luo et al., “The performance of asphalt mixtures modified with lignin fiber and glass fiber : A review,” Constr. Build. Mater., vol. 209, pp. 377–387, 2019, doi: 10.1016/j.conbuildmat.2019.03.126.

[2] A. Chelovian and G. Shafabakhsh, “Laboratory evaluation of Nano Al2O3 effect on dynamic performance of stone mastic asphalt,” Int. J. Pavement Res. Technol., vol. 10, no. 2, pp. 131–138, 2017, doi: 10.1016/j.ijprt.2016.11.004.

[3] R. Tanzadeh, J. Tanzadeh, M. honarmand, and S. A. Tahami, “Experimental study on the effect of basalt and glass fibers on behavior of open-graded friction course asphalt modified with nano-silica,” Constr. Build. Mater., vol. 212, pp. 467–475, 2019, doi: 10.1016/j.conbuildmat.2019.04.010.

[4] H. Zalnezhad, S. S. Galooyak, H. Farahani, and A. Goli, “Investigating the effect of nano-silica on the specification of the sasobit warm mix asphalt,” Pet. Coal, vol. 57, no. 5, pp. 509–515, 2015.

[5] A. Mukhtar, X. Luo, C. Lü, J. Wang, and Z. Huang, “Improving mechanics behavior of hot mix asphalt using graphene-oxide,” Constr. Build. Mater., vol. 254, p. 119261, 2020, doi: 10.1016/j.conbuildmat.2020.119261.

[6] N. F. O, Z. Kordi, and G. Shafabakhsh, “Evaluating mechanical properties of stone mastic asphalt modified with,” Constr. Build. Mater., vol. 134, pp. 530–539, 2017, doi: 10.1016/j.conbuildmat.2016.12.202.

[7] G. H. Shafabakhsh, O. J. Ani, and M. Talebsafa, “Artificial neural network modeling (ANN) for predicting rutting performance of nano-modified hot-mix asphalt mixtures containing steel

slag aggregates," Constr. Build. Mater., vol. 85, pp. 136–143, 2015, doi: 10.1016/j.conbuildmat.2015.03.060.

[8] L. Picado-santos and J. Neves, applied sciences A Review of Nanomaterials ' E ff ect on Mechanical Performance and Aging of Asphalt Mixtures. 2019.

[9] H. Ezzat, S. El-badawy, A. Gabr, and E. I. Zaki, "Evaluation of Asphalt Binders Modified with Nanoclay and Nanosilica," Procedia Eng., vol. 143, no. Ictg, pp. 1260–1267, 2016, doi: 10.1016/j.proeng.2016.06.119.

[10] S. H. Mousavinezhad, G. H. Shafabakhsh, and O. J. Ani, "Nano-clay and styrene-butadiene-styrene modified bitumen for improvement of rutting performance in asphalt mixtures containing steel slag aggregates," Constr. Build. Mater., vol. 226, pp. 793–801, 2019, doi: 10.1016/j.conbuildmat.2019.07.252.

[11] A. Ameli, R. Babagoli, M. Khabooshani, R. Aliasgari, and F. Jalali, "Permanent deformation performance of binders and stone mastic asphalt mixtures modified by SBS / montmorillonite nanocomposite," Constr. Build. Mater., vol. 239, p. 117700, 2020, doi: 10.1016/j.conbuildmat.2019.117700.

[12] M. S. M. Norhasri, M. S. Hamidah, and A. M. Fadzil, "Applications of using nano material in concrete: A review," Constr. Build. Mater., vol. 133, pp. 91–97, 2017, doi: 10.1016/j.conbuildmat.2016.12.005.

[13] A. K. Arshad, E. Shaffie, W. Hashim, F. Ismail, and K. A. Masri, "Evaluation of nanosilica modified stone mastic asphalt," Int. J. Civ. Eng. Technol., vol. 10, no. 2, pp. 1508–1516, 2019.

[14] A. K. Arshad, J. Ahmad, K. A. Masri "Rutting resistance of nanosilica modified porous asphalt," Int. J. Civ. Eng. Technol., vol. 10, no. 1, pp. 2274–2284, 2019

[15] S. Kie, M. Reza, and G. Shafabakhsh, "Experimental investigation of the fatigue phenomenon in nano silica- modified warm mix asphalt containing recycled asphalt considering self- healing behavior," Constr. Build. Mater., vol. 246, p. 117558, 2020, doi: 10.1016/j.conbuildmat.2019.117558.

[16] A. K. Arshad, K. A. Masri, & Ahmad, J. "Investigation on Moisture Susceptibility and Rutting Resistance of Asphalt Mixtures incorporating Nanosilica Modified Binder," Pertanika Journal of Science and Technology, 25, 19–30, 2017.

[17] H. Taherkhani and S. Afroozi, "Investigating the creep properties of asphaltic concrete containing nano-silica," Sadhana - Acad. Proc. Eng. Sci., vol. 43, no. 2, pp. 1–9, 2018, doi: 10.1007/s12046-018-0792-3.

[18] R. Sezavar, G. Shafabakhsh, and S. M. Mirabdolazimi, "New model of moisture susceptibility of nano silica-modified asphalt concrete using GMDH algorithm," vol. 211, pp. 528–538, 2019.

[19] S. Karatzas, "Applications of Nanomaterials in Pavement Engineering : A Review Applications of Nanomaterials in Pavement Engineering : A Review," no. March, 2018.

[20] J. Zhu, K. Zhang, K. Liu, and X. Shi, "Performance of hot and warm mix asphalt mixtures enhanced by nano-sized graphene oxide," Constr. Build. Mater., vol. 217, pp. 273–282, 2019, doi: 10.1016/j.conbuildmat.2019.05.054.

[21] Q. Zeng, Y. Liu, Q. Liu, P. Liu, Y. He, and Y. Zeng, "Preparation and modification mechanism analysis of graphene oxide modified asphalts," Constr. Build. Mater., vol. 238, p. 117706, 2020, doi: 10.1016/j.conbuildmat.2019.117706.

[22] K. A. Masri, H. Awang, R. P Jaya, A. K. Arshad, "Moisture susceptibility of porous asphalt mixture with nano silica modified asphalt binder," IOP Conference Series: Earth and Environmental Science, 224(1), 012028, 2019.

[23] A. K. Arshad, M. S. Samsudin, K. A. Masri, M. R. Karim, A. G. Abdul Halim, "Multiple stress creep and recovery of nanosilica modified asphalt binder," MATEC Web of Conference, 103, 09005, 2017.

Acknowledgments

The authors would like to acknowledge Malaysian Higher Education for funding this research and University Grant number RDU1903146 and RDU190387.