ISSN 2303-4521
Periodicals of Engineering and Natural Sciences *Original Research*
Vol. 10, No. 4, July 2022, pp.32-39

Using nano silica to enhance the performance of recycled asphalt mixtures

Sozan S. Rasheed[1], Hasan H. Joni[1], Rasha H. Al-Rubaee[1]
[1]Highways and Bridges Engineering Branch, Civil Engineering Department, University of Technology, Baghdad, Iraq

ABSTRACT

Understanding how the physical properties of Nano-silica material affect the ultimate implementation of the asphalt binder is an essential study area that has been disregarded previously. The current investigation aims to determine whether or not it was possible to change the asphalt binder with Nano-silica (NS) depending on the qualities of the asphalt binder under consideration. Using nano-silica (2, 4, and 6 percentage by weight of asphalt), a penetration grade asphalt cement with 60/70 was developed. Nano silica and asphalt cement were first tested for their qualities. The NS modified asphalt binder was ready for use in the experiment after being heated to 160°C and mixed with a shear mixer at 2000 rpm for 60 minutes. The softening point temperature and penetration index of the NS modified asphalt binder, as well as the Brookfield rotational viscosity and ductility data, were also evaluated. Based on the rheological performance of the NS modified asphalt binder, increasing Nano silica content increases stiffness while decreasing temperature sensitivity. The addition of 4% Nano silica (NS) asphalt binder improved its basic properties and allowed it to be used in hot weather. By adding 4% NS to the hot recycle asphalt mixture, the Marshall stability is increased by 32.5%, the flow is reduced by 21.4%, the unit weight is maintained, and the amount of air voids in the mix, as well as other mix qualities, are kept at acceptable ranges. It'll also boost the ITS by 37.8%. In general, adding NS to asphalt mixtures improves their qualities.

Keywords: Nano silica, Bitumen, Asphalt Mixture, Modification, RAP.

Corresponding Author:

Sozan S. Rasheed
Civil Engineering Department
University of Technology
Address. Baghdad-Iraq
E-mail: bce.20.23@grad.uotechnology.edu.iq

1. Introduction

Transportation essentially affects the economic growth of the countries [1-6]. Among transportation modes, highways can be considered as the major facility for the movement of the persons and goods [7-11]. Pavement of the highway represents the main component as it carries the traffic loads [9, 12-14]. Therefore, design and construction of tight and durable pavements is in high demand [15-17]. Tight pavements depend mainly on the quality of the asphalt mixture. Hot mix asphalt (HMA) is the most common type used in major highways. The properties of the asphalt play a major role in the quality f the mixture. Enhancement of HMA is essential to produce tight pavements. Several techniques are available for enhancement. Among these techniques, additives are the most popular. Nowadays, there is a high demand on recycling of waste materials in miscellaneous domains [17-21]. Therefore, recycling of flexible pavements is in a vital concern due to the huge quantities of reclaimed asphalt pavements (RAP) accumulated after removal of old pavements. In addition, the usage of Nano materials in enhancement of construction materials greatly increases [22-24]. Mixing between the two approaches (using RAP in asphalt mixtures as a waste material and Nano particles as a modifier) is very interesting to be investigated. Therefore, this study adopted this hybrid approach. A number of studies were implemented in the domain of RAP usage [25, 26] and a number of studies adopted the usage of Nona materials to enhance the properties of bitumen or bituminous mixtures [27-31]. However, adoption of hybrid approaches still in high demand. Therefore, this study aims to investigate the effect of Nano silica on the properties of asphalt materials. In addition, the study aims to investigate the effects of Nano silica on the properties of the asphalt mixtures contain RAP.

2. Materials used

The asphalt was purchased from Dora refinery in Baghdad, Iraq with a penetration grade of 60-70. All properties of the purchased asphalt conform to the Iraqi standard specifications. The aggregate was purchased from Nibaie quarry, north of Baghdad. Table 1 shows the properties of the purchased aggregate. The filler used in this study is limestone dust. It was purchased from Karbala lime industry with a specific gravity of 2.77 and particles finer than 0.075 mm of 94%. RAP was provided from a road in Yarmouk in Baghdad city. The pavement of the mentioned road was removed to a depth of 50 mm. The asphalt content of RAP was determined using extraction test according to ASTM D-2172 and its average value was found to be 4.6%. All RAP particles are smaller than 19 mm and 5.2% of the particles are smaller than 0.075 mm. Nano silica (SiO_2) was purchased from local markets in a form of powder. It has a white color and a hydrophobic surface. Due to large surface area of NS, it may result in an improvement in the viscoelastic properties of asphalt. Table 2 shows the properties of NS used in this study.

Table 1. The properties of the aggregates used

Property	ASTM Designation	Coarse aggregate	Fine aggregate	Specification
Bulk Specific Gravity	C127, C128	2.625	2.567	-
Apparent Specific Gravity	C127, C128	2.618	2.629	-
Percent Water Absorption	C127, C128	0.91	0.91	-
Angularity	D 5821	98 %	-	`Min 90 %
Toughness	C535	21.2%	-	Max. 30%
Soundness	C88	4.1 %	-	Max 12 %

Table 2. The properties of the NS used

Physical Property	Value
Appearance	white powder
Density	24 g/m^3
The average size of the particles	15nm
Specific gravity	2.2 – 2.4
Purity	> 99.9%
Loss of ignition	≤ 6 %
PH value	6.50-7.50
Specific surface area	100 ± 25 m2/g

3. Laboratory investigations

Empirical rheological tests ("penetration grade, Softening Point, penetration index, rotational viscosity, and ductility") were performed on virgin and modified asphalt with varying Nano-silica percentages. The tests were completed in accordance with industry standards. The softening point test assesses the bitumen binder's flowability. The Brookfield rotating viscometer is now commonly used to test asphalt cement viscosity. The SP/pen relationship between penetration value and softening point temperature data can be used to determine bitumen binder temperature sensitivity. The asphalt binder's homogeneity of bitumen binder utilized in this study is demonstrated using a ductility test.

4. Modification process

The bitumen binder was changed by Nano-silica (NS) by heating it to 160 degrees Celsius. Pour the Nano-silica powder into the asphalt binder in weighted amounts of 2, 4, and 6 percent and blend for 60 minutes with a shear mixer at 2000 rpm to achieve a homogenous composition [32].

The attributes of both modified and controlled asphalt recycled mixtures must be defined by Marshall Test is employed. The first set of specimens is made to determine the control mix's parameters, Marshall Test method as per (ASTM D6926-10) and (ASTM D6927 – 15) is used in this research, for the determination of asphalt mix characteristics.

Optimum Asphalt Content (OAC) is calculated by making three HMA sample sets that have been produced at 4.0%, 4.50%, 5.0%, and 5.50% asphalt content and compacting samples with 75 blows with a standard hammer. Three sample sets are constructed with modified asphalt cement containing varying amounts of NS to achieve the appropriate mix characteristics. The aggregates (coarse, fine, and mineral filler) are prepared. From the results, it was found that the optimum asphalt content for the control mix is 5%. Each of the combinations had a ratio of RAP, with a percentage of 20%, based on the overall weight of the mixture (The amount of asphalt in the mixture stayed the same). Table 3 shows the types of aggregate (new and recycled) and asphalt (new and old) in each combination. When recycling is included in the combination, a sieve examination of RAP material was performed during the manufacturing of asphalt mixes. the RAP components were oven-dried before being combined with the dried and warmed new aggregate at the prescribed manufacturing temperatures. For an hour before mixing with (AC) to ensure that all material reached the optimum manufacturing temperature.

Table 3. Percentages of RAP and asphalt in the mixtures

Mixture	Aggregate (%)		Binder content (%)	
	New aggregate	RAP	New	RAP
HMA - 0% RAP	100	0	5.0	0
HMA - 20% RAP	80	20	4.08	0.92

5. Testing program of mixtures

The testing program includes indirect tensile strength (ITS) and moisture susceptibility evaluation. The indirect tensile strength test was adopted to evaluate the resistance of samples (control and modified) against fracture. The test is conducted by the method of ASTM D6931. Asphalt mixture samples were prepared in the same procedure as the Marshall specimen except that in this test the specimens were placed in a 25°C water bath for 30 min before the implementation of the tensile strength testing. After that, the specimen was positioned on the vertical diametrical level. The ITS test is loaded at a rate of 50.8 mm/min until the sample is cracked. The maximum load is recorded at the time of fracture.

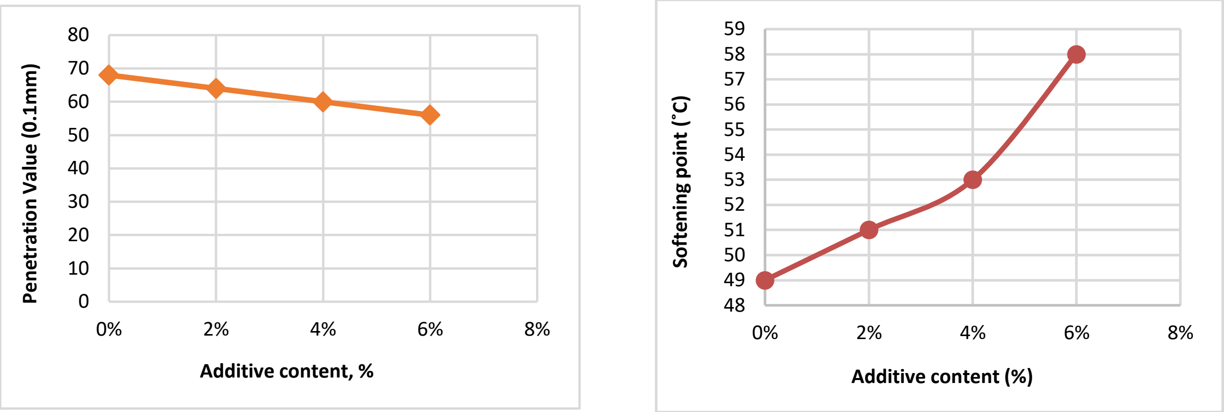
To evaluate the moisture susceptibility of the mixture which refers to mixture damage under moisture effect, testing was implemented using ASTM D4867. A group of six specimens for each type of binder were prepared in Marshall mold with air voids range of (6-8), Three samples were kept in a water bath at 25℃ for 30 minutes to prepare for ITS, and an average value of ITS for these specimens was represented by sdry (ITS for un-conditioned specimens). The remaining three samples were characterized in a volumetric container (4000 ml) full of water at a temperature of 25℃, and a vacuum of (3.74 KPa) was applied for (5 to 10) min, to obtain a (55 to 80 %) degree level of saturation. The specimens were placed for (24 hours) in a water bath at (60℃), after that, they were translated to (25℃) in a water bath for (1-2 hr.). Finally, they were subjected to an indirect tensile strength test. The mixture should have the lowest tensile strength ratio of 80%.

6. Result and discussion

6.1 Effect of NS on asphalt

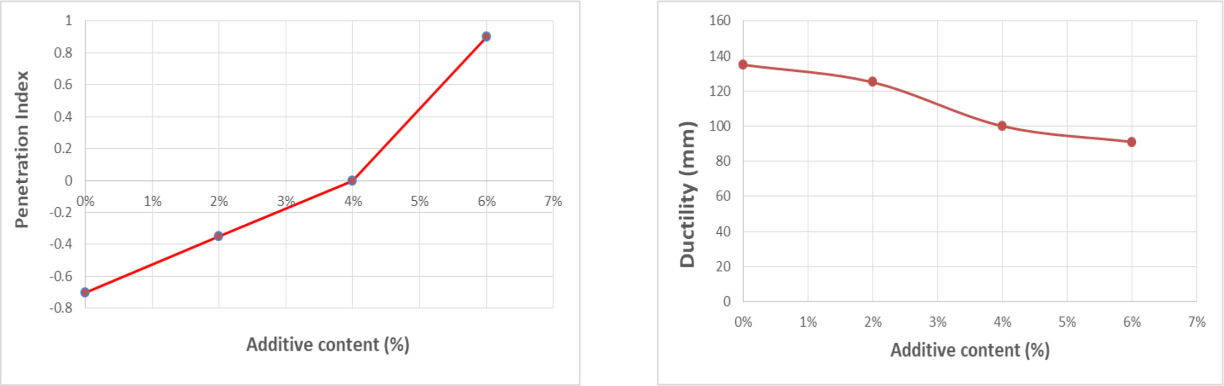
Figure 1 shows the effects of NS on the properties of asphalt. Figure 1(a) shows the relationship between the asphalt penetration values and Nano-silica contents. It is obvious that when the NS content increases, the penetration value decreases. Low asphalt penetration values indicate increased hardness and stiffness. Nano-silica adsorption and diffusion in the asphalt cement binder absorb light volatiles and increases the Asphaltene phase [33]. This leads to the Nano-silica particles having a greater stiffness than the asphalt cement binder, resulting in a stiffer NS modified asphalt binder than previously. Figure 1(b) shows the effect of NS on softening point of asphalt. It is clear that when the NS percent grows, the softening point rises as well. When temperature susceptibility decreases, the softening point temperature rises, which indicates that the temperature susceptibility has decreased. It is through the Asphaltene section that light asphalt volatiles is absorbed and transformed into resin material, which leads to the NS [32, 33] attributable to these outcomes. Furthermore, because Nano silica particles have a higher stiffness than asphalt cement binder, the stiffness of NS modified asphalt binder is increased, it was determined that Nano-silica influenced the hardness and stiffness of asphalt binder material. The temperature susceptibility of the asphalt binder is measured by the penetration index (PI). Temperature susceptibility diminishes as penetration index increases, and stiffness increases. In Figure 1(c), the

PI fluctuates with NS content can be viewed. The value of PI for NS modified asphalt increases incompatibility with the amount of Nano-silica. However, adding NS reduced the temperature sensitivity of the asphalt binder. NS modified asphalt can be utilized for highway paving when the temperature is between (+2.0 and -2.0) [33]. The cohesiveness of the mixture is determined by the ductility of the asphalt cement binder. Figure 1(d) shows the relationship between the ductility of asphalt and the amount of Nano-silica present. The figure illustrates that as the amount of Nano-silica raises, the ductility value drops, which is consistent with the findings of prior studies [32, 34]. At high temperatures, a rotating viscosity test is performed to determine the asphalt binder material's intended workability (throughout the mixing and compacting process). The viscosities of the non-modified and NS modified asphalt at various NS percentages in a temperature range of 135–165°C, as illustrated in Figure 1(e) and Figure 1(f). When NS is added to the NS modified asphalt binder, the viscosity increases. Enhanced viscosity values are associated with increased stiffness of NS asphalt and increased NS diffusion and adsorption in asphalt binder material [32]. When constructing a road with a high traffic load, it is advised that a high viscosity asphalt binder be used.



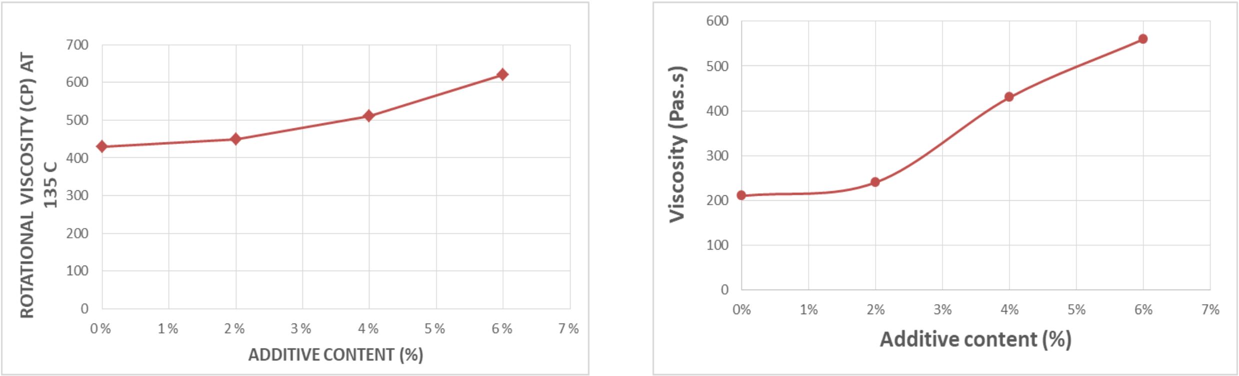
(a) Effect on NS on penetration

(b) Effect of NS on softening point



(c) Effect of NS on penetration index

(d) Effect of NS on Ductility



(e) Effect of NS on rotational viscosity

(f) Effect of NS on absolute viscosity

Figure 1. The effects of NS on the properties of asphalt

6.2 Effect of NS on HMA with RAP

The effects of NS on the properties of HMA mixed with 20% RAP are described in this subsection. Figure 2 shows the effect of NS on Marshal Stability. Compared to the original hot recycled mixes, it can be seen that the stability increases with the increase of NS dose up to 4% of NS. However, increasing the NS dose decreases the Marshall Stability. As evidenced by the physical and rheological test findings, this outcome may be attributable to the mixture stiffening. Furthermore, the use of recovered asphalt pavement increases Marshall Stability and flow properties by improving the mixture bond (cohesion and adhesion) of the NS modified asphalt binder as well as the high rigidity and stiffness.

Figure 3 shows the effect of NS on Marshall Flow values mixtures samples. The results shown in Figure 3 clarify an obvious reduction in Marshall Flow with the increase in NS dose up to 4%. Afterward, increase in NS dose increases the Marshall Flow. This behavior can be attributed to the increment of asphalt mix stiffness, which increases Marshall Stability as a consequence of the Silica influence upon the binder characteristics.

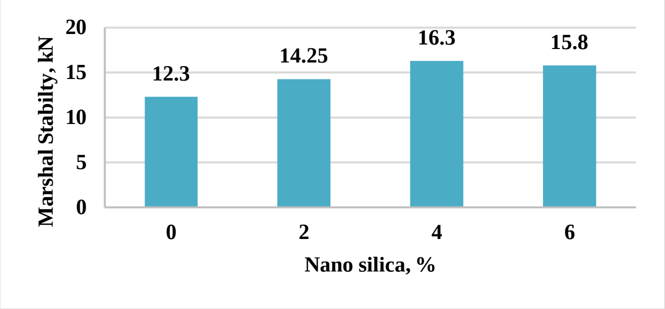


Figure 2. The effect of NS on Marshall Stability values of HMA mixed with 20% RAP

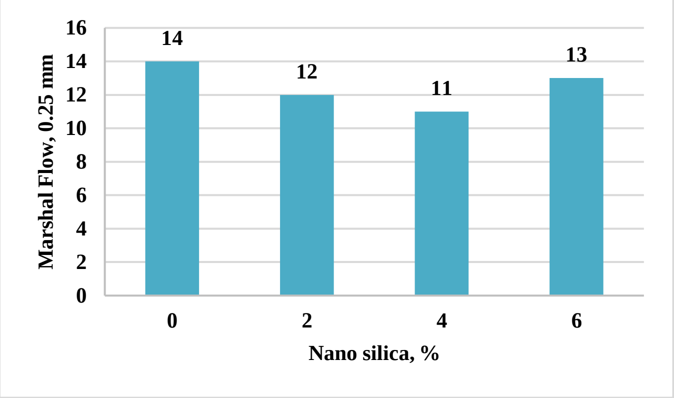


Figure 3. The effect of NS on Marshall Flow values of HMA mixed with 20% RAP

Figure 4 shows the effects of NS on ITS values of HMA mixed with 20% RAP for unconditioned and conditioned samples. Indirect tensile strength values increase with increase of hot recycled mixes modified with NS were increased in comparison to the original mix. This is due to the fact that the mixture, which has been changed with NS components, stiffened the binder as the viscosity increased. The tensile strength ratio (TSR) was increased compared to the original mix as well, lowering the danger of moisture. This increasein tensile strength and TSR is due to the addition of silica, which forms a thick layer of asphalt around the aggregate particles and thus prevents water from reducing the bondingstrength between the modified asphalt and aggregate and increases the cohesion of the mixture.

Figure 5 shows the tensile strength ratio (TSR). As shown in the figure, the values of ITS increases with the increase of the NS dose up to 4%. Afterward, TSR values decreases with increase of NS dose. This increase in tensile strength and TSR is due to the addition of silica, which forms a thick layer of asphalt around the aggregate particles and thus prevents water from reducing the bonding strength between the modified asphalt and aggregate and increases the cohesion of the mixture.

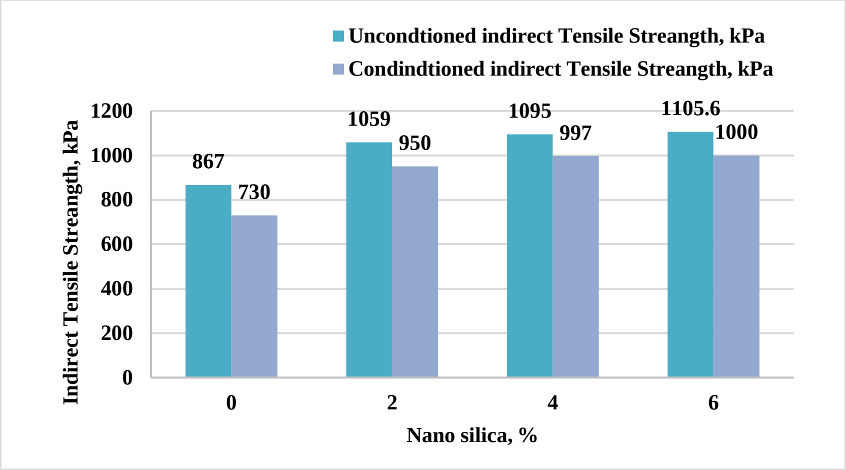


Figure 4. The effect of NS on ITS values of HMA mixed with 20% RAP

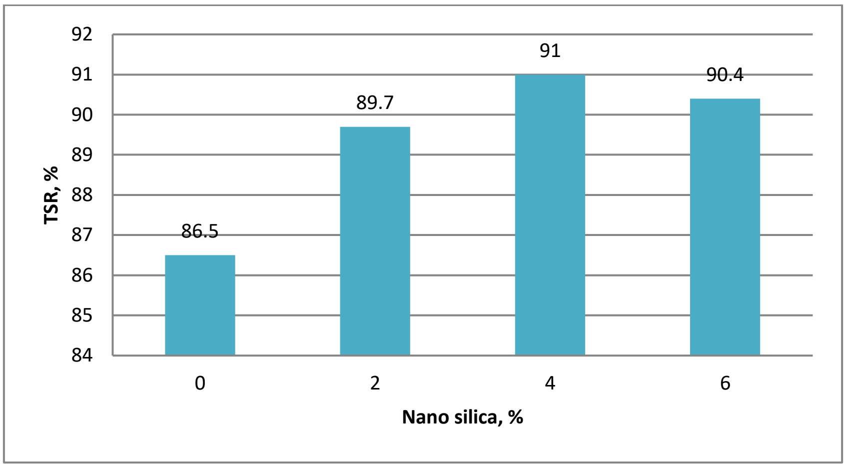


Figure 5. The effect of NS on TSR values of HMA mixed with 20% RAP

7. Conclusions

1. At moderate temperatures, the penetration value of asphalt binder material decreases as the amount of NS in the binder material increases.
2. Even as Nano-silica % rises, the softening point of asphalt binder material rises, indicating that asphalt binder hardness rises as well.
3. Nano-silica reduces the penetration index of asphalt binder material and hence its temperature sensitivity.
4. The Stiffness of NS-modified asphalt increases as the Nano-silica content and agglomerate of NS modified asphalt binder material rises, indicating that its ductility decreases as the Nano-silica percentage increases.
5. The asphalt cement binder's standard properties were improved by adding 4% Nano-silica by weight of asphalt. Using a asphalt binder was a better choice as the temperature increased. As measured by a higher softening point temperature and a lower viscosity value, penetration values were lower.
6. Marshall Stability is increased by 32.5 % and flow is reduced by 21.4 % when the asphalt mixture is modified with 4% NS. Furthermore, it was discovered that the tensile strength, as well as the ratio of the tensile strength of modified asphalt, is improved when compared to non-modified asphalt. The ITS value increased by 37.8%. In terms of water sensitivity, all of the mixes that were made with the NS modified binders had higher TSR values.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

Funding information

No funding was received from any financial organization to conduct this research.

References

[1] A. M. Mosa, L. A. Salem, and Q. S. Banyhussan, "Overcoming Concreting Problems of Rigid Pavements using Knowledge-Based System," Civil Engineering Beyond Limits, Vol. 2, pp. 12-17, 2021.

[2] A. A. Mohammed, K. Ambak, A. M. Mosa, and D. Syamsunur, "A Review of the Traffic Accidents and Related Practices Worldwide," The Open Transportation Journal, Vol. 13, pp. 65-83, 2019.

[3] A. A. Mohammed, K. Ambak, A. M. Mosa, and D. Syamsunur, "Expert System in Engineering Transportation: A Review," Journal of Engineering Science and Technology, Vol. 14, pp. 229-252, 2019.

[4] A. A. Mohammed, K. Ambak, A. M. Mosa, and D. Syamsunur, "Traffic Accidents in Iraq: An Analytical Study," Journal of Advanced Research in Civil and Environmental Engineering, Vol. 5, pp. 1-13, 2018.

[5] A. M. Mosa, R. Atiq, M. Raihantaha, and A. Ismail, "Classification of construction problems in rigid highway pavements," Australian Journal of Basic and Applied Sciences, Vol. 5, pp. 378-395, 2011.

[6] A. A. Mohammed, K. Ambak, A. M. Mosa, and D. Syamsunur, "Classification of Traffic Accident Prediction Models: A Review Paper," International Journal of Advances in Science Engineering and Technology, vol. 6, pp. 35-38, 2018.

[7] M. K. Hatem, A. M. Mosa, and M. H. Al-Dahlaki, "Software for Line of Balance in Projects of Highways," Journal of Engineering and Sustainable Development, Vol. 22, pp. 119-130, 2018.

[8] A. M. Mosa, M. R. Taha, A. Ismail, and R. A. O. K. Rahmat, "An Educational Knowledge-based System For Civil Engineering Students in Cement Concrete Construction Problems," Procedia - Social and Behavioral Sciences, Vol. 102, pp. 311-319, 2013.

[9] A. M. Mosa, M. R. Taha, A. Ismail, and R. A. O. K. Rahmat, "A diagnostic expert system to overcome construction problems in rigid highway pavement," Journal of Civil Engineering and Management, Vol. 19, pp. 846-861, 2013.

[10] A. M. Mosa, R. A. O. K. Rahmat, A. Ismail, and M. R. Taha, "Expert System to Control Construction Problems in Flexible Pavements," Computer-Aided Civil and Infrastructure Engineering, Vol. 28, pp. 307-323, 2013.

[11] A. M. Mosa, R. Atiq, M. Raihantaha, and A. Ismail, "A knowledge base system to control construction problems in rigid highway pavements," Australian Journal of Basic and Applied Sciences, Vol. 5, pp. 1126-1136, 2011.

[12] Q. S. Banyhussan, S. A. Tayh, and A. M. Mosa, "Economic and Environmental Assessments for Constructing New Roads: Case Study of Al-Muthanna Highway in Baghdad City," in AWAM International Conference on Civil Engineering AICCE2019, Penang, Malaysia, 2020.

[13] A. M. Mosa, "Neural Network for Flexible Pavements Maintenance and Rehabilitation," Applied Research Journal, Vol. 3, pp. 114-129, 2017.

[14] A. M. Mosa, N. N. Ismail, N. I. M. Yusoff, M. A. Mubaraki, N. A. Memon, M. R. Taha, and M. R. Hainin, "An expert system to remedy concrete imperfections and their effects on rigid pavements," Jurnal Teknologi, Vol. 76, pp. 105-119, 2015.

[15] A. M. Mosa, A. H. Taher, and L. A. Al-Jaberi, "Improvement of poor subgrade soils using cement kiln dust," Case Studies in Construction Materials, Vol. 7, pp. 138-143, 2017.

[16] A. M. Mosa, Q. S. Banyhussan, and R. A. Yousif, "Improvement of expansive soil properties used in earthworks of highways and railroads using cement kiln dust," Journal of Advanced Civil Engineering Practice and Research, Vvol. 4, pp. 13-24, 2017.

[17] A. M. Mosa, "Modification of Subgrade Properties Using Waste Material," Applied Research Journal, Vol. 3, pp. 160-166, 2017.

[18] A. M. Mosa, M. H. Al-Dahlaki, and L. A. Salem, "Modification of roadbed soil by crushed glass wastes," Periodicals of Engineering and Natural Sciences (PEN), Vol. 9, pp. 1038-1045, 2021.

[19] A. M. Mosa, "Modification of Hot Mix Asphalt Using Polyethylene Therephthalate (PET) Waste Bottles," SUST Journal of Engineering and Computer Sciences, Vol. 18, pp. 62-73, 2017.

[20] A. Mosa, I. Jawadb, and L. Salema, "Modification of the Properties of Warm Mix Asphalt Using Recycled Plastic Bottles," International Journal of Engineering, Vol. 31, pp. 1514-1520, 2018.

[21] A. M. Mosa, L. A. Salem, and W. A. Waryosh, "New Admixture for Foamed Warm Mix Asphalt: A Comparative Study," Iranian Journal of Science and Technology, Transactions of Civil Engineering, Vol. 44, pp. 649-660, 2020.

[22] L. A. Salem, A. H. Taher, A. M. Mosa, and Q. S. Banyhussan, "Chemical influence of nano-magnesium-oxide on properties of soft subgrade soil," Periodicals of Engineering and Natural Sciences, Vol. 8, pp. 533-541, 2020.

[23] A. M. Mosa, "Influence of Nano and Ordinary Particles on Properties of Subgrade: a Comparative Study," Journal of Engineering Sciences, Vol. 45, pp. 411-421, 2017.

[24] L. A. Salem, A. H. Taher, and A. M. Mosa, "Enhancement of Subgrade Properties Using Magnesium Oxide for Pavement Construction," International Journal of Engineering & Technology, Vol. 7, pp. 321-324, 2018.

[25] S. Liu, A. Shukla, and T. Nandra, "Technological, environmental and economic aspects of asphalt recycling for road construction," Renewable and Sustainable Energy Reviews, vol. 75, pp. 879-893, 2017/08/01/ 2017.

[26] L. Noferini, A. Simone, C. Sangiorgi, and F. Mazzotta, "Investigation on performances of asphalt mixtures made with Reclaimed Asphalt Pavement: Effects of interaction between virgin and RAP bitumen," International Journal of Pavement Research and Technology, Vol. 10, pp. 322-332, 2017.

[27] C. Maduabuchukwu Nwakaire, S. Poh Yap, C. Chuen Onn, C. Wah Yuen, and H. Adebayo Ibrahim, "Utilisation of recycled concrete aggregates for sustainable highway pavement applications; a review," Construction and Building Materials, Vol. 235, pp. 1-10, 2020.

[28] J. Tanzadeh and R. Shahrezagamasaei, "Laboratory Assessment of Hybrid Fiber and Nano-silica on Reinforced Porous Asphalt Mixtures," Construction and Building Materials, Vol. 144, pp. 260-270, 2017.

[29] L. Sun, X. Xin, and J. Ren, "Asphalt modification using nano-materials and polymers composite considering high and low temperature performance," Construction and Building Materials, Vol. 133, pp. 358-366, 2017.

[30] R. Li, F. Xiao, S. Amirkhanian, Z. You, and J. Huang, "Developments of nano materials and technologies on asphalt materials – A review," Construction and Building Materials, Vol. 143, pp. 633-648, 2017.

[31] Z. Kordi and G. Shafabakhsh, "Evaluating mechanical properties of stone mastic asphalt modified with Nano Fe2O3," Construction and Building Materials, Vol. 134, pp. 530-539, 2017.

[32] H. H. Zghair, H. Jony, and M. Hassan, "Rheological Characteristics of Nano Silica Modified Asphalt Binder Material," in 2019 International Engineering Conference (IEC), Erbil, Iraq, 2019.

[33] H. Taherkhani and S. Afroozi, "The properties of nanosilica-modified asphalt cement," Petroleum Science and Technology, Vol. 34, pp. 1381-1386, 2016.

[34] E. H. Fini, P. Hajikarimi, M. Rahi, and F. Moghadas Nejad, "Physiochemical, rheological, and oxidative aging characteristics of asphalt binder in the presence of mesoporous silica nanoparticles," Journal of Materials in Civil Engineering, Vol. 28, pp. 1-10, 2016.