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A Review on Physical and Rheological Properties of Nano Zinc Oxide Modified Asphalt Mixture

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Abstract: In road construction the selection of mixed materials is important. Therefore, use of additives on asphalt as a modification material has been introduced since past year. The purpose of this study was to evaluate the performance characteristics for rutting reacting with nano-ZnO as a mixed material in asphalt. In this research, were focus for a result from previous study regarding the suitable percentage to sort up. This case study conduct with gradation of aggregate with AC14 of marshal mix design test and conventional test such as penetration test and softening point test. For sort up the result were extract data from previous study regarding the performance of nano-ZnO with asphalt binder. Then, the result will be compared between the previous study. Based on the result, it was found that when the penetration is decrease, the softening point of bitumen is increase. In conclusion, the results show that the addition of ZnO particles can improve the rutting resistance of the asphalts. The reduction in ZnO particle size has significant positive impacts on the asphalt mixture.

Keywords: Rutting, Modified Binder, Nano-ZnO,

1. Introduction

In this era, road use is a priority for consumers. Roads were created to connect several important locations. In addition, to make it easier for users to use the technology created. But every road has their own problem factor of pavement defects and failures. There are several examples of specific distresses problem on pavement occur. In this study, it focused to rutting pavement defects and the performance characteristics on rutting with nano Zinc Oxide (nano-ZnO) as modified asphalt mixture. Rutting commonly occurs when the road requires to hold the heavy load from vehicle. But the main effect of this problem is not about vehicle, but it occurs because of the aggregate and binder in asphalt that make the road can move from origin [1]. In Malaysia, defect and failure of rutting road is quite famous occur

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at road pavement. the surface of rutting pavement is deform become a longitudinal permanent. Inside this finding of an accident due to pavement condition. Moreover, rutting defect can contribute to an accident [2]. Rutting occur because of the depth of rut pavement is greater than the ordinary ratio [3]. Besides that, weather condition also can be affecting the roughness of rutting under the rainy weather [4].

In this research, nano-ZnO is selected as a modifier mixture to transform new nano technology use. The function of nano-ZnO is to improve anti-aging property of asphalt. Therefore, this research to find out the performance of nanotechnology react in rutting problem. The chemical reaction such as nano particle gives a good result and reaction between chemical and physical were occurred during the process of the modification process [5].

There are several tests in pavement such as hot mix asphalt (HMA) performance tests, and asphalt mixture performance test. HMA is the most widely used type of pavement on the market, although the earliest varieties of hot-mix asphalt as we know it were invented in France in the mid-1800s. The first HMA road in the United States was not built until 1870, when the state of New York became the first to do so. Once it was established that HMA was a long-lasting and cost-effective method of paving roads, the market boomed in terms of popularity, competition, and efficiency. A batch of HMA is composed of aggregate and a viscous binding agent, and it is manufactured at temperatures ranging from 300°C to 350°C. Dense-graded mixes, stone matrix asphalt, and open-grade mixes are the three subcategories of high-performance asphalt [6].

The aim of this study is to evaluation on rutting performance characteristics of nano-ZnO modified asphalt mixture. Therefore, find out the suitable optimum percentage of nano-ZnO use in asphalt binder. This case study conduct with gradation of aggregate with AC14 of marshal mix design test.

2. Literature Review

There are various of journal and references focus regarding to an experiment of nanomaterial in nano-ZnO as modified asphalt mixture of road highway. In road construction, before starting the construction material use will be decided to ensure the road can use for long term and good in-service life. Moreover, asphalt work has an agent in binder to glue the particle of aggregate and asphalt binder to form asphalt mixture. The characteristic of asphalt binder in performance of asphalt mixture based on its temperature susceptibility, stability to resist the rutting under load and workability to be compact [7].

Therefore, in this study, nanomaterial is selected to an experiment to look up the performance in rutting problem. The result of nanomaterial with nano silica mixture performance in road construction such as safety in motion and friction. Also, durability in enhance of compressive quality. In addition, nanomaterial can make it an economic and sustainable in road construction. Nanomaterial can decrease the overall of maintenance cost and cut down temperature for the advancement methodology [8].

2.1 Asphalt mixture

Asphalt mixtures are composed of coarse aggregate, fine aggregate, filler, and asphalt in a predetermined ratio. Attributed to the fact that asphalt mixture is a typically temperature-sensitive substance, changes in its mechanical features and operational performance will be significant when temperatures fluctuate significantly. Under varied temperature circumstances, the asphalt mixture will behave in a slightly different manner. When the temperature is raised over a certain point, the viscosity of the binder and the adhesion between the aggregates both decrease considerably. Meanwhile, the

stiffness of the asphalt mixture is decreasing, and a significant amount of accumulated and irreversible deformation will occur because of each repetition of loading [9].

The asphalt mixture using a nanotechnology such as fibers and polymers give a positive result which is this material can make the temperature of rutting increase. Moreover, it can moderate the fatigue temperature and decrease the temperature of cracking occur in pavement. In other words, enhancing the pavement structure's durability. In additions, Fibers and other additives reduce the amount of hardship imposed by recurring heavy traffic loading on pavements throughout the course of their useful life [10].

2.2 Asphalt Binder

Bitumen penetration grade 60/70 is semi-hard penetration grade bitumen that is used as paving grade bitumen. Figure 1 show the specification of bitumen penetration grade 60/70. Table 1 is listing the characteristics of the bitumen and test methods. Based on the result it shows that grade 60/70 bitumen has a higher optimal density which can be attributed to the higher asphalt component necessary for mixes [11].

Table 1: Characteristics of the bitumen and test methods (Qasrawi H et al, 2016)

Property	Specification	Test method	Test value
Bitumen 60/70			
Specific gravity @25/25 C	1.01-1.06	ASTM D70	1.02
Penetration @25 C	60-70	ASTM D5	64
Softening point	49-56	ASTM D36	53
Ductility @25C	100 MIN	ASTM D113	134
Loss on heating (Wt)%	0.2% MAX	ASTM D6	0.12%
Flash point C	250 MIN	ASTM D92	320
Solubility in Cs2 (Wt)%	99.5% MIN	ASTM D4	99.9%

2.3 Nano Zinc Oxide (nano-ZnO)

The characteristic of nano-ZnO it is form in white powder. Moreover, nano-ZnO can be classify as an additive in numerous of material and it is insoluble in water. To improve the qualities of various materials, nano-sized particles have been used in a variety of applications for many years. Table 2 shows the physical properties of nano-ZnO [13].

Table 2: Physical properties of nano-ZnO

(Hamedi G.H, 2015)

Properties	Nano ZnO
Crystal structure	Zinc blend
Shape of particle	Cubic
Density (g/cm³)	5.5-5.6
Refractive index	2
BET specific surface area (m²/g)	40 ± 5
Average grain size (nm)	≈20
Bulk density (g/cm³)	0.28-0.48
pH	8.5-9.5
Water (%)	≤0.7

3. Materials and Methods

The methodology part, often known as the materials and methods section, contains all the information required to sort up the research results. Furthermore, this grade of bitumen is often utilised in asphalt mix manufacture. Furthermore, permanent deformation or rutting occurs because of repetitive loading produced by heavy traffic, resulting in the accumulation of permanent deformation under repeated tyre pressures.

3.2 Methods

3.2.1 Data Collection

In this study, case study analysis was chosen as the method. The goal of the case study in this study is to collect and compare enough data on this topic. One of the goals of this study is to find the optimum percentage of nano-ZnO as modified in asphalt binder. In order to do so, information regarding existing the effects of nano-ZnO size on rutting resistance of asphalt The data for this study came from secondary sources, which means information gathered from sources that have already been published in some manner. Secondary data was gathered from other academics' study journals, internet articles, published censuses, and other statistical data.

3.2.2 Data Analysis

The data was analysed using a comparison of data from case studies. The actual percentage is difficult to find out without doing the laboratory, so the percentage is determined by comparing the quantitative data that can be collected in any sources. Among the factors that is considered when making this analysis is the percentage of nano-ZnO, and the conventional test such as penetration test and softening test.

4. Results and Discussion

The results and discussion section presents data and analysis of the study. This section can be organized based on the stated objectives, different experimental configurations from several previous journal.

4.1 Results

4.1.1 The Effect of nano-ZnO on Rheological Characteristic of Asphalt Binder

The result of effectiveness of nano-Zno with asphalt thru the Dynamic Shear Rheometer (DSR) test. The DSR test was used to investigate the physical properties characteristics of ZnO as modified asphalt binders when exposed to high temperatures. The dynamic shear modulus (G), phase angle (d), and anti-rutting factor (G/sind) of the asphalt binder were all measured during the DSR test at the specified testing temperature and loading frequency. The findings of the DSR test are presented in Table 3.

Table 3: Results of DSR tests on nano-ZnO modified asphalt

(Zhang H.L et al, 2018)

Property		Matrix asphalt	ZnO Modified Asphalt		
Factor	Temperature (℃)		80 nm	350 nm	2 μm
G (kpa)	64	1.0164	1.605	1.489	1.312
	70	0.4917	0.7321	0.6667	0.617
	76	0.2892	0.3641	0.345	0.3171
	82	0.1293	0.1958	0.1822	0.1763
$\delta(°)$	64	88.12	85.71	85.51	85.79
	70	85.85	85.24	84.07	84.42
	76	83.77	82.25	81.36	81.01
	82	76.81	73.61	73.11	74.64
G'/sin$\delta(kPa)$	64	1.0169	1.6095	1.4936	1.3155
	70	0.4930	0.7346	0.6703	0.6199
	76	0.2909	0.3675	0.3490	0.3210
	82	0.1328	0.2041	0.1904	0.1828

In this study, the researchers discovered that adding nanoparticles to asphalt binder improved the behavior properties of the asphalt binder and reduced rutting in the asphalt mix samples. The nanoparticles were evenly distributed throughout the asphalt binder region and had a beneficial impact on the rutting performance of the asphalt mixes in this study. The one of an objective aim to achieve the result in this study is to evaluate the rutting of asphalt samples prepared with a modified asphalt binder incorporating 4% with nanoparticles. Therefore, the conclusion of this research found out adding the nanoparticles can give a decreased risk of rutting in asphalt mix samples as compared to asphalt mix sample without nanoparticles [16].

4.2 Discussions

4.2.1 Conventional Test

The effect of ZnO particle in penetration and softening test give a positive feedback in this experiment which is when the size of the ZnO particles is decreased, the penetration is lowered down, and the softening point is increased slightly. The softening point is at its maximum when the dosage of ZnO particles is 4% [15].

In this experimental study, a pure asphalt binder with a penetration grade of 60/70 from the Isfahan mineral oil refinery was used as the binder. Conventional test procedures, such as the penetration test, softening point test, and ductility test, were used to characterise the properties of the base and modified asphalt binders. Table 4 lists the engineering qualities of asphalt binder, which are important in the construction of roads. The tests performed on the asphalt binder samples were repeated three times on different samples to ensure that the results were accurate. The asphalt binder was mixed with the nano ZnO for 4–5 minutes at 130–140 ° C and 14000 rpm per minute in a batch with a diameter of 15 cm and a height of 30 cm [13].

Table 4: Results of the experiments conducted on the base and modified asphalt binders Asphalt (Hamedi G.H et al, 2015)

Asphalt binder	Penetration grade (mm/10)	Softening point (℃)	Viscosity, mPas			Ductility (cm)	Flash point (℃)
			115 ℃	135 ℃	150 ℃		
Base asphalt binder	69	47	0.776	0.289	0.156	112	313
Modified asphalt binders							
2 % nano ZnO	65	52	0.897	0.331	0.179	>150	321
4 % nano ZnO	63	51	0.960	0.334	0.179	115	323

5. Conclusion

As a conclusion, the performance of nano-ZnO as modifier in asphalt binder experiment conduct with penetration test and softening test. The result shows when the penetration is decrease, the softening point of bitumen is increase. These asphalts can efficiently utilize of ZnO particles, and the reduction in ZnO particle size has a strong positive effect on the anti-rutting factor of asphalts, according to the studies. Nanoparticles were uniformly distributed throughout the asphalt binder region and had a positive impact on the rutting performance of the asphalt mixtures. Moreover, rutting is a common type of damage that occurs to asphalt mixes, particularly when temperatures are high. The temperature sensitivity of the asphalt binder is the primary reason for the occurrence of this type of damage. Besides that, the use of nanomaterials such as nano-ZnO in industry is highly encouraged as it has been proven about the properties of the material.

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