The Evaluation of the Performance of Nano Bauxite Powder (NBP) Modified Asphalt Binder

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Abstract. For the first time, this study assessed the rheological and physical properties of asphalt binder combined with nano bauxite powder (NBP) derived from raw Malaysian bauxite. The physical properties were evaluated via conventional tests like softening point, penetration, rotational viscosity and ductility, while the impacts of NBP modified asphalt binders on rheological properties were assessed via dynamic shear rheometer (DSR). In addition, the morphology (nanoparticles size and shape) of the NBP was studied using transmission electron microscopy (TEM). The results show that using of NBP as a modifier increases the hardness of the asphalt binder and improves its physical properties. Compared with unmodified asphalt binder, there was ~11% enhancement in softening point and ~16% decrease in penetration of modified asphalt binders. In a similar manner, compared with base asphalt binder, there was increase in G* and G*/sin δ values for the modified asphalt binders and decrease in δ values, which suggests that there was an enhancement in the resistant property of the modified asphalt binders to permanent deformation (rutting). Therefore, to alter asphalt binder's properties, NBP is considered as an optimum additive.

Keywords: Nano bauxite powder · Physical proprieties · Dynamic shear rheometer and TEM

1 Introduction

With growing population worldwide, there has also been an increase in the number of vehicles globally, particularly in developed countries, which has resulted in a lot of pavement issues [1]. Asphalt pavement has to be able to withstand the loads in various climatic conditions, existing heavy loads and expected future loads for an acceptable

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period. Therefore, to reduce the pavement distresses, the asphalt binder and asphalt mixes need to be enhanced. As early as the 1950s, the application of asphalt modifiers has been applied in the road structure industry to improve the performance of asphalt pavement [2]. Modifiers such as fillers, fibres, extenders polymer, oxidants, and nanocomposites materials had been applied for several years in asphalt binder to improve its properties.

Nanotechnology is microscopic particles of material, it is new materials that recently become popular and one of the large and important parts of research and development worldwide. It has been lighted on and used to control the problems in the design and construction of practical structures [3]. Nanotechnology is also defined as micro-scale fillers which can make improvements in the performance of the asphalt binder [4]. The asphalt pavement system can reap various benefits by employing nanotechnology as a modifier in asphalt mixture and asphalt binder. Some of the benefits include decrease in moisture damage, enhancement of asphalt properties during high and low temperatures, durability improvement of the asphalt mixture, energy saving and decrease in maintenance costs [3, 5–7].

In previous research studies, the performance of asphalt binder modified with different types of nanomaterials have been described. In addition, various papers have been published evaluating the performance of asphalt binder modified with polymers like EVA, SBR or SBS. However, in the literature, there is limited information regarding the NBP-modified asphalt binder's characteristics. Various contents of nanosilica were employed [8] to modify the asphalt binder. They found acceptable performance at high temperature with modified asphalt binders, suggesting it is better suited for high load traffic roads and high temperature regions. Additionally, [9] employed nano ZnO with various sizes of nanoparticles (average diameter of 2, 80 and 350 nm) to examine the performance of mixture and asphalt binder. The results of experimental evaluation show that the moisture susceptibility, flexural tensile strengths and low temperature bending strains of asphalt mixtures are improved with decreasing of ZnO particle size. Generally, an improvement in the performance grade leading to higher resistance to rutting deformation was obvious. The performance of nano bauxite powder-modified asphalt binder has been evaluated in this study considering modified asphalt binders' rheological and physical properties.

2 Experimental Design

2.1 Materials

We used asphalt binder 80/100 penetration grade as control asphalt binder, provided by Petronas Company (Malaysia). The raw material Malaysian bauxite was obtained from KK Best Metal Sdn. Bhd. Kuantan, Pahang, Malaysia, which is employed as a modifier to the asphalt binder.

2.2 Sample Preparation

2.2.1 Production of Nano Bauxite Powder (NBP)

The raw supplied bauxite was first ground into a specific powder size using LAAV machine and then, it sieved using a 75 μm sieve. Subsequently, the powder was dried at temperature 145 °C for getting rid of the moisture. After that, the bauxite powder was heated at 125 °C in an oven for 30 min. Thereafter, using a bowl mill machine the bauxite powder ground for 5, 10 and 15 h to measure the optimum grinding time.

2.2.2 Preparation of Modified Asphalt Binder

Into the base asphalt binder, addition of nano bauxite powder (NBP) was done in three different concentrations, namely 3, 5 and 7% NBP by weight of the asphalt binder. A high shear mixer at a speed of 3000 rpm was employed for mixing all modified asphalt binders. During the mixing process (approximately 60 min), temperature within the range of 160 ± 3 °C was maintained.

2.3 TEM

Transmission electron microscope (TEM, Hitachi HT7700) with high magnification and image resolution (1 nm) was employed to investigate the morphology (nanoparticles shape and size) of NBP.

2.4 Physical Properties

When evaluating the performance of the modified asphalt binder, the physical properties are critical parameters. The property changes of the asphalt binder modified with NBP, by comparing with the original asphalt binder, were assessed through physical tests such as ductility (ASTM D5), penetration (ASTM D5) and the softening point (ASTM D113).

2.5 Viscosity

The flow characteristics of the asphalt binder were assessed through the rotational viscosity test to get an initial idea if it can be handled and pumped when performing hot mixing. This study employed a Brookfield rotational viscometer to describe the modified and unmodified asphalt binder viscosity. Based on Superpave test parameters (Asphalt Institute 2007), the viscosity was measured by testing all samples with a spindle No. 27 that has a constant rotational speed of 20 rpm and maintained under temperatures of 135 and 165 °C.

2.6 Rheological Properties

The rheological properties of the unmodified and modified asphalt were determined by employing Dynamic Shear Rheometer (DSR). For all binders, a plate with a diameter of 25 mm and thickness of 1 mm was employed to characterise the viscous and elastic behaviour of asphalt binder at intermediate and high service temperatures conforming to AASHTO T315. Moreover, the impacts of employing NBP modified asphalt binders were investigated by measuring the phase angle (δ), complex modulus (G*) and rutting resistance parameter (G*/sin δ) of asphalt binder.

3 Results and Discussions

3.1 TEM

Figure 1 shows the TEM images of the NBP, with ellipsoidal nanoparticles while, the grain size distribution of the NBP during the grinding time which obtained from the TEM images is shown in Fig. 2. The agglomeration of nanoparticles in the micrograph attributed to the high surface energy and strong surface tension of ultrafine nanoparticles. Moreover, the fine particle size resulted in a large surface area, which enhanced the catalytic activity of the nanoparticle. The NBP grain sizes were 300–325, 125–150, and 10–20 nm for the grinding time durations of 5, 10, and 15 h, respectively. Grinding duration time of 15 h was selected as the optimum duration time to produce a nano bauxite powder with major nanoparticles size ranging from 10 to 20 nm.

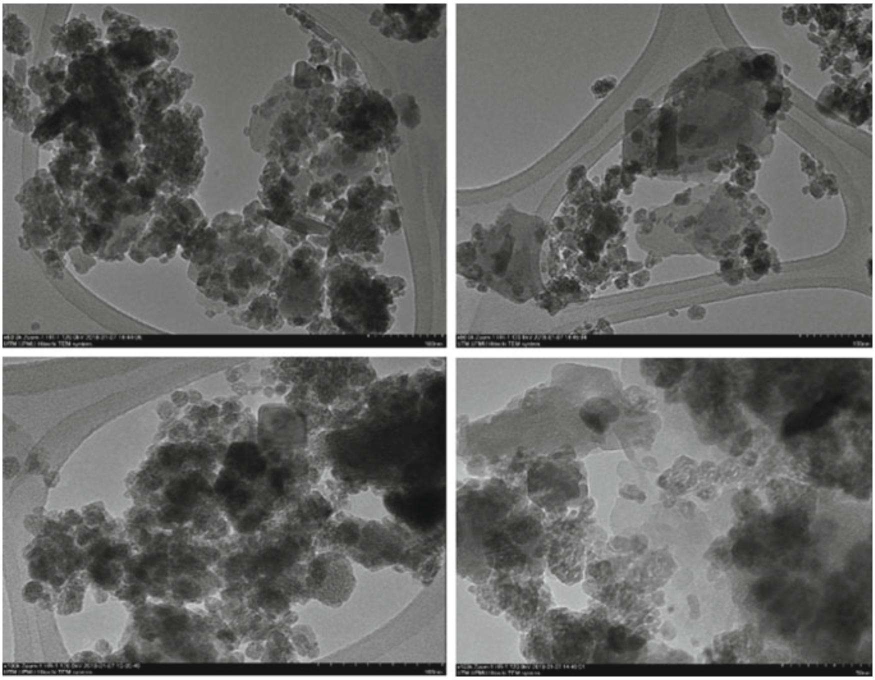

Fig. 1. Transmission electron microscopy (TEM) images of the nano bauxite powder (NBP)

3.2 Physical Properties

The impact of employing NBP as an additive along with the asphalt binder was recorded for the modified asphalt binder samples as physical properties. Figure 3 shows the relationship between the point values for ductility, penetration and softening and the NBP concentration. Rise in the NBP concentration was seen to cause a reduction in penetration values, which suggest that the modified asphalt binder has

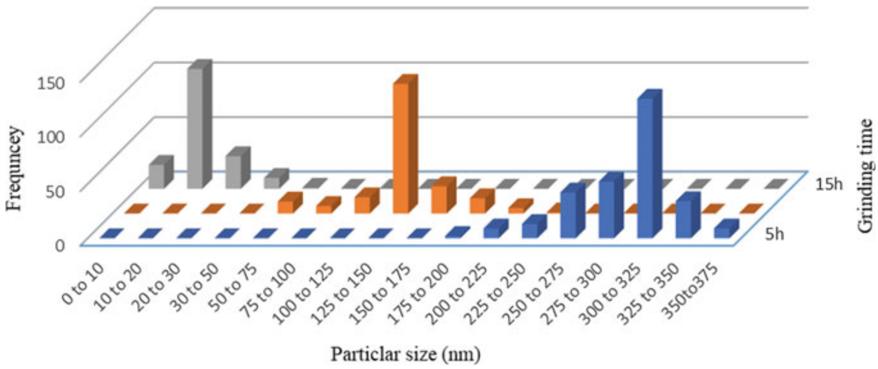

Fig. 2. Particular size distribution of the NBP during grinding time obtained from TEM images

become stiffer. Moreover, a reduction in the ductility values was seen due to increase in MBP concentration, as a result of the modified asphalt binder becoming stiffer. Moreover, the modified asphalt binders' softening point was improved because of increase in modified asphalt binder's hardness.

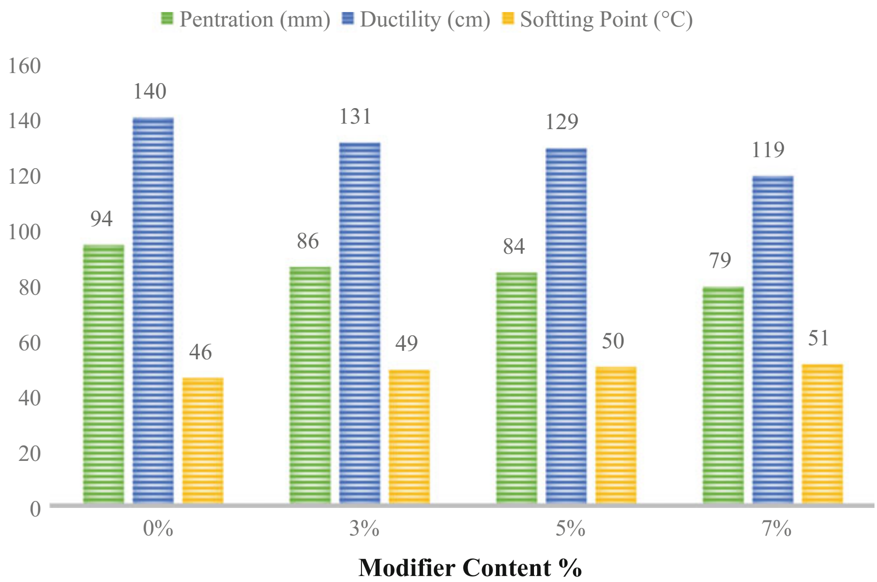

Fig. 3. Physical properties of base and modified asphalt binder

3.3 Viscosity

Figure 4 presents the rotational viscosity values for the base as well as modified asphalt binder. On adding NBP to the asphalt binder, the viscosity value was seen to increase at test temperatures (135 and 165 °C). The hardening effect of NBP led to increase in viscosity. Furthermore, the NBP layers' better dispersion in the base binder could also result in increase in viscosity value of the modified asphalt binder, which results in strengthening the bonding by restricting the asphalt flow. All these ultimately lead to increase in the hardness of the asphalt binder and enhancement of its physical properties.

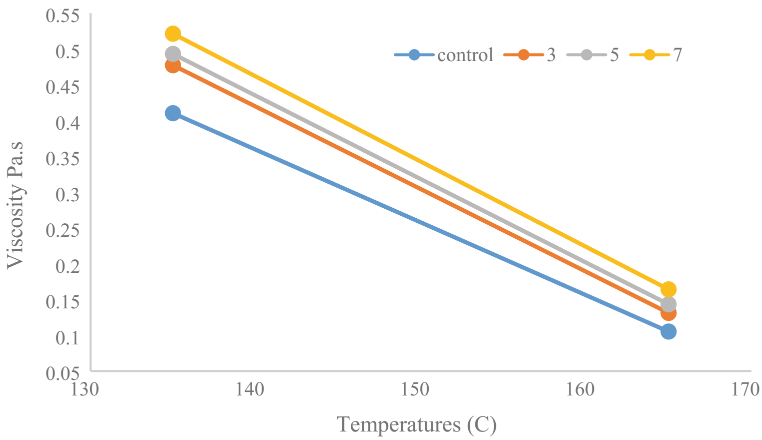

Fig. 4. Base and modified asphalt binder's viscosity

3.4 Rheological Properties

Complex modulus (G*) is also referred to as the asphalt binder's total resistance to rutting deformation, where the higher the value of G*, the greater will be the resistance to permanent deformation. Figure 5 shows the test temperature together with the complex modulus (G*) for the base and modified asphalt binder with NBP. The increase in G* value in the modified asphalt binder was observed. As seen in Fig. 5, it is obviously that 5% NBP has the highest value of complex modulus G* among the binders while the base binder has the lowest G* value, which means the modified asphalt binder with NBP has higher resistance to permanent deformation compared with the base asphalt binder.

The phase angle (δ) represents the angle between the strain and stress under the loading frequency, and it also relies on the temperature of the test. The phase angle (δ) is an indicator for defining viscous and elastic behaviours of the asphalt binder, in which the greater the value of δ, the higher the viscous behaviour it will display. Meanwhile, the low δ value represents higher elastic behaviour. Figure 6 presents the phase angle (δ) together with the test temperature for the unmodified and modified asphalt binders. The δ values for all modified asphalt concentrations reduced when compared with the base asphalt binder, which suggests that the addition of NBP improves the elastic behaviour. Also, as noted in Fig. 6, 5% NBP has the lowest value of δ compared to with the other percentages of the modified asphalt binder which means it has the highest elastic properties and is more resistant to rutting deformation.

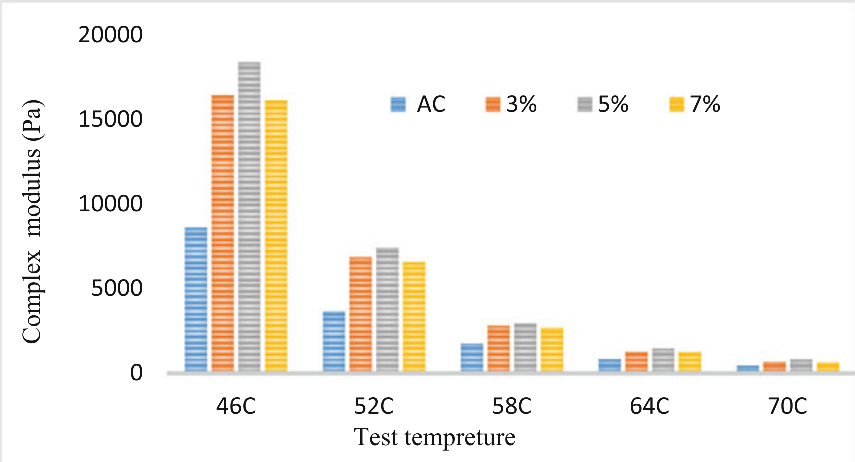

Fig. 5. Test temperature alongside the complex modulus (G*)

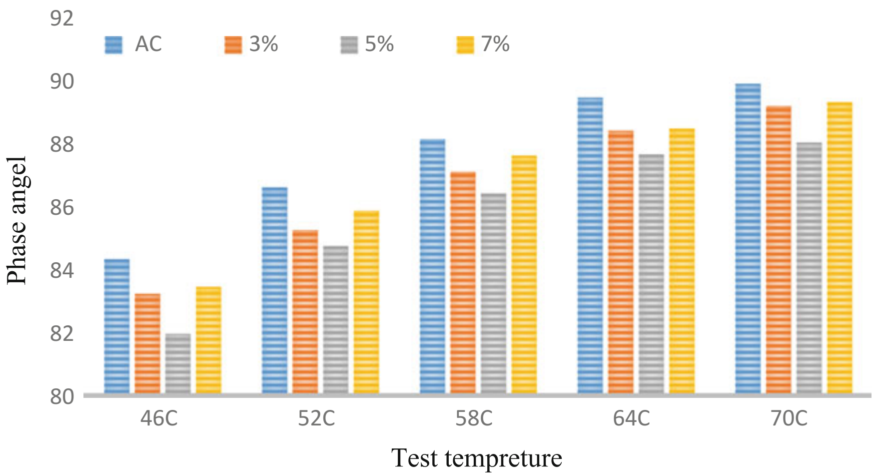

Fig. 6. Test temperature alongside the phase angle (δ)

Referring to the previous studies [10, 11], the rutting resistance of the asphalt binder can be characterised with the value of G*/sin δ at high temperatures. The superpave technique requires the minimum value for G*/sin δ to be 1 kPa for the rutting parameter of unaged samples [12]. Also, enhanced permanent deformation resistance pavement is confirmed with a higher value of G*/sin δ. As displayed in Fig. 7, the lowest value of G*/sin δ was associated with the base asphalt binder while the highest value of G*/sin δ was associated with the 5% NBP. Furthermore, for all the modified asphalt binder concentrations associated with NBP, an increase in G*/sin values was observed, which suggests enhanced permanent deformation resistance by employing NBP modified asphalt binder.

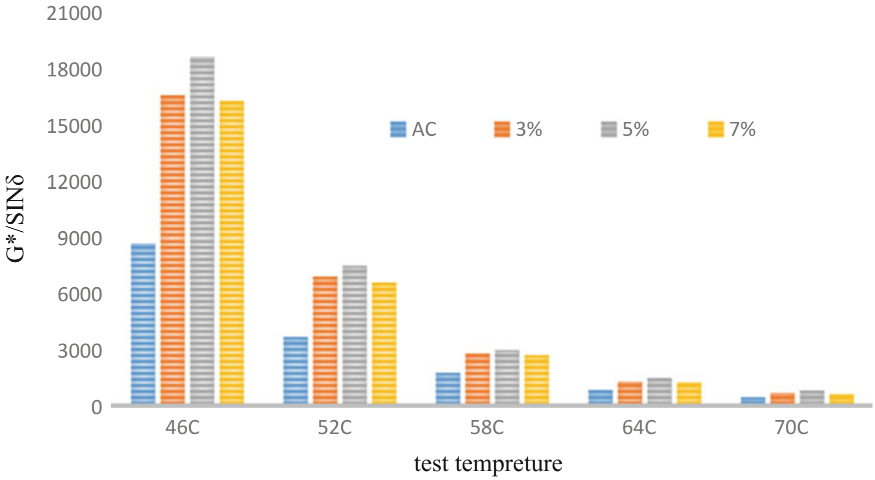

Fig. 7. Temperature's impact on permanent deformation (rutting)

4 Conclusion

The study included various tests for ductility, penetration and softening point, rotational viscosity and dynamic shear rheometer (DSR) to assess nano bauxite powder modified asphalt binder's performance. The following conclusions have been derived according to the obtained results:

i. NBP was successfully produced by grinding the raw bauxite for 15 h. TEM images showed the existence of ellipsoidal nanoparticles with a grain size ranging from 10 to 20 nm.
ii. As seen through conventional tests, employing NBP increased the stiffness of the modified binders, which also suggests enhancement of their temperature susceptibility, and improved softening point for all modified binders than with the base asphalt binder.
iii. There was an increase in viscosity values for all modified asphalt binders than with the base asphalt binder, which also improved the physical properties of the asphalt binder as well as increases its hardness.
iv. When compared with the base asphalt binder, there was an increase in the values of G* and G*/sin δ for the modified asphalt binders along with a decrease in δ values, which suggests enhanced resistance to permanent deformation (rutting).

In general, enhancement in the rheological and physical properties of asphalt binder was seen when the NBP-modified asphalt binder was employed. Further, the optimum percentage that is considered for the modifier can therefore be 5% NBP.

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