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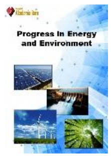

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Short communication

Optimizing the combination of nitrile-butadiene rubber and styrene-butadiene-styrene for modification of asphaltic pavement

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Abstract

Modification of asphaltic pavements using nitrile-butadiene rubber (NBR) and styrene-butadiene-styrene (SBS) has been studied in recent years to improve pavement performance and durability while reducing waste from disposal of nitrile gloves. However, in previous studies, the uses of NBR and SBS were evaluated in isolation hence, their use in combination has not been considered. Therefore, in an attempt to use NBR and SBS in combination for modification of asphaltic pavements, hot-mix asphalt (HMA) samples containing varying dosages of NBR and SBS were prepared. Volumetric measurements and Marshall tests were conducted on the samples. Results suggest the incorporation of NBR and SBS at 6 and 5% dosages, respectively, by weight of the bitumen in the HMA, as the optimal combination. The combination led to the highest stability and lowest flow of the HMA, which contribute to the highest increase in stiffness hence highest improvement in strength.

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1 Introduction

In road construction, incessant traffic loads in tandem with environmental stresses on the pavement will result in deformations that lead to problems in the long run. At high temperature, the pavement becomes soft and the loads may lead to rutting. On the other hand, at low temperature, the pavement becomes stiff and the loads may lead to cracking. When the deformations occur, water can seep into voids within the pavement, resulting in losses in strength and durability. In order to reduce or even prevent the deformations, flexible pavement was often selected for road construction as it can return to its original form after experiencing the loads hence has the capability to distribute the loads. As asphalt is flexible, it is adopted as a constituent of asphaltic pavements, which act as flexible pavements. In an effort to increase the flexibility and softening point of asphaltic pavements, it is common that polymers are added to the mixes to develop polymer-modified asphalts [1,2].

Modification of asphaltic pavements using nitrile-butadiene rubber (NBR) has been studied in recent years to improve pavement performance and durability while reducing waste from disposal of nitrile gloves. NBR is a type of synthetic rubber that is commonly employed in the rubber industry as a replacement for natural latex. NBR has resilient properties, making it an attractive option as an alternative material for the production of disposable rubber gloves. The COVID-19 pandemic led to a rise in the production of the gloves [3]. As they are disposable, their waste also increased accordingly.

Previous studies [1,4] on the addition of NBR into bituminous concrete revealed that the material can be used commercially in the road construction industry. NBR has been found to possess higher oil resistance, toughness, flexibility, abrasion resistance, resilience and temperature flexibility than natural rubber [1,4]. It has a moderate tensile strength and a high electrical conductivity, and is resistant to heat and chemicals [4]. Hence, it has the potential to improve the physical and mechanical performances of asphaltic mixes.

At the same time, in the road construction industry, styrene-butadiene-styrene (SBS) has been widely employed in an effort to increase the performance of asphaltic pavements. SBS possesses high temperature stability, low temperature crack and fatigue resistances [5], has the capacity to withstand applied stress without deforming [6], and exhibits a balance between handling and performance characteristics [6]. It has also been found that adding SBS to asphaltic mixes improved the stiffness and resistance to rutting and fatigue cracking while the asphalt demonstrated higher resistance to ageing and environmental factors, such as water and ultraviolet radiation [7].

Although recent studies have attempted to evaluate the performance of asphaltic pavements with modifications using NBR and SBS, their uses were evaluated in isolation hence, their use in combination has not been considered. Therefore, in an attempt to use NBR and SBS in combination for modification of asphaltic pavements, hot-mix asphalt (HMA) samples containing varying dosages of NBR and SBS were prepared. Volumetric measurements and Marshall tests were conducted on the samples to determine the optimal combination and its effect on the pavement performance.

2 Materials and Methods

HMA samples containing aggregates and binder, which contains bitumen and varying dosages of NBR and SBS, were prepared. The NBR was incorporated at 5, 6, 7 and 10% by weight of the bitumen. Control samples, which do not contain NBR and SBS, were also prepared. Marshall tests were conducted on the HMA samples to determine the optimum NBR dosage. The SBS was then incorporated, at 4 and 5% by weight of the bitumen, into the binder that contains NBR at the optimum dosage.

The aggregate gradation complies with the specifications of Public Works Department of Malaysia based on the gradation limits for asphaltic concrete 14 [8]. A total mass of 1,200 g of aggregates was prepared for each sample. The aggregate gradation of the mix design is shown in Table 1.

Table 1 Aggregate gradation of the mix design

Sieve Size (mm)	Passing (%)	Retained (%)	Mass Retained (g)
14.000	95	5	60
10.000	81	14	168
5.000	56	25	300
3.350	47	9	108
1.180	26	21	252
0.425	18	8	96
0.150	10	8	96
0.075	6	4	48
Filler	0	6	72

NBR was obtained in shredded, reprocessed form from Green World Recycling Sdn. Bhd., which is a manufacturer based in Penang, Malaysia, that serves for the reclaimed rubber industry. The NBR was cut into smaller pieces of about 3 mm in size before being mixed into bitumen of a penetration grade of 60/70 for two hours at 3,000 rpm at 150 °C using a shear mixer.

SBS was obtained from Sigma-Aldrich, which is a chemical, life science and biotechnology company based in Missouri, United States. The SBS was mixed for 30 minutes at 4,000 rpm at 180 °C using the shear mixer.

Weighing, heating, mixing and compacting of the mix were performed in preparation for the Marshall tests. The aggregates and binder were placed in the oven and heated at 150 °C. The temperature was monitored consistently throughout mixing. The mix was loaded into 100-mm diameter steel moulds and then compacted using the Marshall compaction machine with 75 blows on each side. The sample was then extruded and left to cool before performing volumetric and Marshall tests.

2.1 Determination of the optimal binder content based on volumetric test results

The optimal binder content was determined based on the volumetric test results for the control samples. The volumetric test yields the bulk unit weight, voids in mineral aggregates, voids in the mixture and voids filled with bitumen. The optimal binder content was adopted to determine the total mass of binder in each sample.

2.2 Determination of the optimal combination of nitrile-butadiene rubber (NBR) and styrene-butadiene-styrene (SBS) based on stability and flow

The Marshall test was performed to determine the stability and flow. The samples were placed into a water bath that was heated to 60 °C and left for 30 minutes, while the Marshall apparatus was conditioned in the oven at the same temperature and duration. The samples were then placed into the mould of the apparatus. Once loaded into the apparatus, a constant load of 50.8 mm/min was applied to the sample. Once the samples deform and fail, the stability and flow were determined. The optimal combination of NBR and SBS was determined based their effect on the stability and flow.

3 Results and Discussion

3.1 Stability and flow at different NBR dosages

Fig. 1(a) reveals that incorporation of NBR resulted in adequate stability except for that at 5% dosage, while Fig. 1(b) reveals that the incorporation resulted in adequate flow. The adequacy in stability and flow are determined based on specifications of Public Works Department of Malaysia [8], where stability of above 8 kN and flow of between 2 and 4 mm have to be obtained for the HMA to be employed as flexible pavement. Incorporation of NBR at 6% dosage led to the highest stability and lowest flow hence is considered as optimal. The optimal dosage obtained is in agreement with the 6% obtained in Chopra and Singh [4], which was determined based on stability and flow values as well as stripping percentages. Additionally, the optimal dosage also falls within the 5–14% range recommended based on the findings of Deepa and Laad [1], which resulted in an increase in the softening point by 3.4% while improving the recovery percentage by 7.3%.

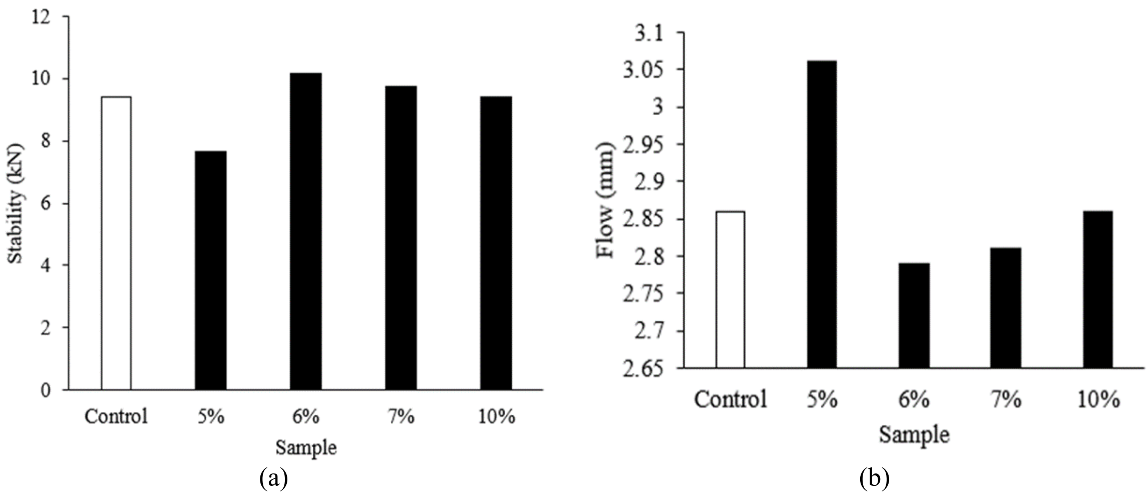
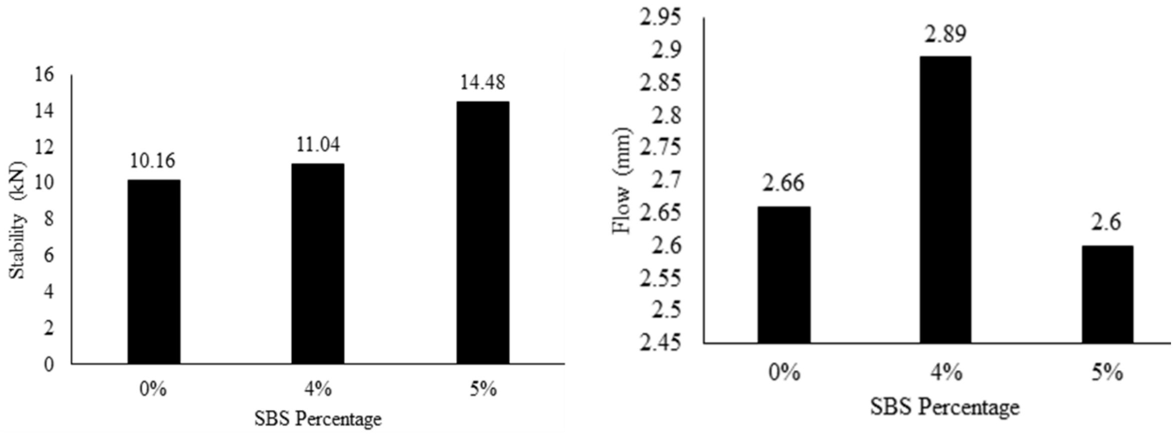


Fig. 1 (a) Stability and (b) flow of control and HMA samples at different NBR dosages.

3.2 Stability and Flow at the Optimal NBR Dosage and Different SBS Dosages

Fig. 2 reveals that, incorporation of SBS at the 6% NBR dosage resulted in adequate stability and flow. Incorporation of SBS at 5% dosage led to the highest stability and the lowest flow hence can be considered as optimal. Even though the addition of NBR and SBS in combination has not been considered in previous studies, according to previous studies that adopted SBS in isolation, the optimal dosage of SBS falls within the 4–9% range recommended in Li et al. [6] based on a review of multiple studies. However, Li et al. [6] suggested a higher shearing time about 40 minutes at 4,000 rpm and a higher temperature of 180 °C to be adopted when mixing SBS into the bitumen due to the tendency for rubberized asphalt to segregate and possess high viscosity.

Therefore, incorporation of NBR and SBS at 6 and 5% dosages, respectively, is considered as the optimal combination as it led to the highest stability and lowest flow of the HMA, among other combinations. The highest stability and lowest flow contribute to the highest increase in stiffness hence highest improvement in strength. As previous studies have not considered the addition of NBR and SBS in combination and only evaluated their additions in isolation, the optimal dosages of NBR and SBS added in combination as obtained in the present study can be considered as novel findings that contribute to advancing the research on developing polymer-modified asphalts.



(a) (b)

Fig. 2 (a) Stability and (b) flow of control and HMA samples at 6% NBR dosage at different SBS dosages.

4 Conclusion

Volumetric measurements and Marshall tests were conducted on HMA samples containing varying dosages of NBR and SBS to determine the optimal combination. Results suggest incorporation of NBR and SBS at 6 and 5% dosages, respectively, as the optimal combination. The combination led to the highest stability and lowest flow, which contribute to the highest increase in stiffness hence highest improvement in strength.

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Declaration of Conflict of Interest

The authors declared that there is no conflict of interest with any other party on the publication of the current work.

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