Effect of Treated Coconut Shell and Fiber on the Resilient Modulus of Double-layer Porous Asphalt at Different Aging

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Abstract. Coconut shell (CS) and coconut fiber (CF) are new waste products that have been of growing interest recently in the highway asphalt pavement industry. This study investigated the effect of CS and CF on the resilient modulus of double-layer porous asphalt (DLPA). CS aggregate 5 mm in size was substituted for the DLPA at 5%, 10%, and 15% by weight, while CF was added to the asphalt at 0.3% and 0.5% by weight. Before mixing with other aggregates, the CS and CF were treated with 5%wt Sodium hydroxide (NaOH) to reduce their water absorption ability. The samples were prepared via the Marshall method. The result shows that DLPA with 10% CS aggregate has better resilient modulus under 25 °C for unaged and aged samples compared with the other substitution percentages. However, the sample with CF has a lower resilient modulus because the amount of CF has increased. In general, the substitution of 10% CS provided better resilient modulus among the other percentages.

1. Introduction

Double-layer porous asphalt (DLPA) was first introduced in the 1990s by European countries [1]. Some countries, such as Italy, the Netherlands, Germany, and Denmark, have investigated the DLPA for further phase development. DLPA can combine the noise-reduction properties of a fine porous mix at the top layer and the drainage effect of a surface course at the bottom layer [2]. In Malaysia, coconuts are one of the most important and oldest plants in the agro plant industries [3]. However, an estimated 3.18 million tons of coconut shells (CS) are produced annually as solid waste that contributes to global pollution [4]. According to Yerramala et al. [5], CS can be used as coarse aggregate in concrete, while Al-Mansob et al. [6] has used CS as additive in asphalt pavement. Dried CS contains 33.61% cellulose, 36.51% lignin, 29.27% pentosans, and 0.61% ash [7]. CS has low ash content but high volatile matter, approximately 65%–75% [8]. It also has better resistance against impact, crushing, and abrasion compared to other conventional crushed granite aggregates [9]. With the exception of the water absorption test, CS can be mixed directly with an asphalt mixture in experiments [10] because it develops from lignocelluloses, which have high polarized hydroxyl group [11]. Agunsoye et al. [12] found that CS treated by Sodium hydroxide (NaOH) has lower water absorption ability than untreated CS. Additionally, the hardness of CS increases after being treated.
with NaOH. Coconut fiber (CF) can reduce the bleeding of the binder and provide a high macro texture of the coating on the asphalt pavement surface [13]. It has many benefits as well when react with asphalt mixtures, as it can ameliorate the mechanical characteristics and enhance the adhesion between surface drainage and tires [14]. Compared to jute and sisal, CF contains the lowest cellulose content at about 36%–43% but with twice the amount of lignin (41%–45%), which gives it high resistance and hardness [15]. CF will act as a stabilizing additive when added into the asphalt mix at around 180 °C [16]. Do Vale et al. [17] conducted a research on the application of CF in stone matrix asphalt mixtures. The research was carried out using two percentages of CF, 0.5% and 0.7%. The flow parameter was tested, and the results shown in Table 1 reveal that the flow parameter with fiber is lower than that without fiber, and 0.7% CF achieves the lowest flow parameter. The result proves that CF can reduce the flow of the asphalt binder and thus decrease the clogging of air void by the binder.

| Fiber  | Fiber content (%) | Flow parameter (%) |
|--------|-------------------|--------------------|
|        |                   | T= 165 °C       | T= 180 °C       |
| Without fiber | 0.0               | 1.06             | 0.70             |
| Coconut | 0.5               | 0.08             | 0.25             |
|         | 0.7               | 0.04             | 0.09             |
| Cellulose | 0.3               | 0.01             | 0.03             |
|         | 0.5               | 0.01             | 0.02             |

The main objectives of these investigations were to observe the resilient modulus of unaged and aging asphalt mixtures by replacing 5 mm coarse aggregates with different percentages of CS (0%, 5%, 10%, and 15%) and adding 0%, 0.3%, and 0.5% CF by weight. All the specimens were prepared using the design binder content of PG-76 modified bitumen.

2. Methodology

2.1. Samples preparation

The DLPA mix was made up of two layers, a 20 mm-thick top layer and a 50 mm-thick base layer. The aggregate size for the top layer was nominal maximum aggregate size (NMAS) size 10 mm while that for the base layer was NMAS size 14 mm. The amount of aggregate for the top and base layers were calculated based on the Marshall density of single-layer porous asphalt. The total amount of aggregate necessary to yield a 70 mm specimen is approximately 1000 g. Based on the ratio of the thickness for a DLPA, the top layer needed 285 g of aggregate, while the bottom layer needed about 715 g [16].

2.2. Treated Coconut Shell and Fiber

The freshly discarded CS and CF were collected from the local oil mills and they were first cleaned and sun dried for one week before being crushed and sieved. However, to reduce the water absorption ability of the materials, CS and CF were soaked and stirred into a 5%wt NaOH aqueous solution for 1 hour at room temperature. The CS and CF were then filtered out and washed several times with distilled water until they had less NaOH, that is, until the water no longer showed any alkalinity reaction. Afterward, the CS and CF were dried in an oven at 60 °C for 24 hours [18].

2.3. Mix Design

The compaction method was carried out in two steps at 2x50 blows. The base layer aggregate was mixed, placed in the Marshall mold, and then transferred into the oven to maintain its temperature.
The top layer was prepared and placed on top of the base layer mix. Each face of the mix was compacted with 50 blows. The compacted specimen then underwent the aging test, which was based on Transfund New Zealand Research Report No. 265 [19]. The samples were wrapped with wire mesh to avoid collapse [20] and then left in the oven for 7 days at 60 °C. Three samples each for the unaged and aged samples underwent the resilient modulus test for different conditions and different components.

2.4. Optimum Bitumen Content
The binder contents used for different mixing proportions of the modified DLPA were based on their respective design binder contents. The optimum binder content was tested and found for each percentage of CS. The results showed that 4.5% binder content was used for the original specimen, while 5.0% binder content was used for the 5%, 10%, and 15% CS replacement specimens.

2.5. Resilient modulus test
The resilient modulus test can be used to assess pavement mix response to traffic loading. The test was conducted by measuring the indirect tensile strength in repeated loading or pulse using Universal Material Testing Apparatus (UMATTA). Each specimen was tested at 25°C after 4 hours conditioning, while the test procedures conformed to those stipulated in ASTM D7369 [21]. Initially, the samples were subjected to 5 condition pulses; beyond which a 1200N peak load was applied along the vertical diameter of the sample. The pulse period and pulse width applied for this test were 3000ms and 100ms respectively with 50ms rise time.

3. Results and Discussion

3.1. Unaged
Figure 1 shows the resilient modulus of unaged modified DLPA with different replacement contents of CS and CF. The result shows that samples with 0.3% CF had the highest resilient modulus followed by those with 0.5% CF and 0% CF. This finding reveals that a specific amount of CF added into asphalt mixtures can help increase the resilient modulus while a high amount of CF will decrease the resilient modulus of asphalt mixtures. Figure 2 shows that the resilient modulus increased when the CS content increased. However, the resilient modulus decreased in the samples with 15% CS replacement, while samples with 10% CS substitution had the highest resilient modulus compared to the other samples. Figures 1 and 2 likewise illustrate that the asphalt mixture with 10% CS replacement and 0.3% CF replacement had the highest resilient modulus. However, a comparison between the replacement of CS and the additives of CF show that CS replacement has greater effect on the resilient modulus of asphalt mixtures than CF additives. This finding is attributed to the considerably lower resilient modulus of the modified asphalt mixtures with 15% CS compared with that of the other mixtures, even those with CF additives.
Figure 1. Resilient modulus at unaged condition for coconut shell DLPA mix

Figure 2. Resilient modulus at unaged condition for coconut fiber DLPA mix

3.2. Long term aging
Figure 3 shows the result of the resilient modulus of long-term aging asphalt mixtures with different CS replacement. The result shows that the 10% CS replacement had the highest resilient modulus, followed by the 5%, 0%, and 15% CS replacements. The resilient modulus of long-term aging asphalt mixtures with different CF additives is shown in Figure 4. The result indicates that the CF additives do not contribute to the resilient modulus after long-term aging. The resilient modulus decreased as the amount of CF increased. The results show that long-term aging asphalt mixtures had lower resilient modulus than unaged asphalt mixtures. However, 10% CS replacement still had the highest resilient modulus for both aged and unaged samples. On the other hand, the unaged samples with 0.5% CF had a lower resilient modulus when compared to those with 0.3% CF.
4. Conclusion
Asphalt mixtures with 10% CS replacement have the highest resilient modulus for unaged and long-term aging results. CS replacement can help increase the resilient modulus of asphalt mixtures. However, if CS replacement is more than 15%, resilient modulus will decrease. The addition of 0.3% CF helps increase the resilient modulus for unaged asphalt mixtures. However, the CF additive does not improve resilient modulus for long-term aging asphalt mixtures. Asphalt mixtures with 10% CS replacement and 0.3% CF additives have the highest resilient modulus compared to other mixtures with modified unaged DLPA. For long-term aging DLPA, the asphalt mixtures with 10% CS replacement and 0% CF additives have the highest resilient modulus.
5. References

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