Short Term Aging Effect of Asphaltic Concrete Incorporating Charcoal Ash from Coconut Shell

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Abstract. Numerous studies have been conducted to improve the performance of asphalt mixture properties in comparison with conventional mixes. One of the alternatives is utilizing waste agriculture product as additive or replacement into bitumen mixture. Coconut shell is one of the agricultural wastes that can be utilized. This paper aims to study the effect of asphaltic concrete incorporating charcoal ash from a coconut shell under short term aging condition. Charcoal coconut shell ash (CCSA) was added into a bitumen with 0%, 2%, 4%, 6%, and 8% by weight. The original CCSA was initially ground until getting the particles sizes less than 0.075mm. Laboratory simulation of aging was applied in this investigation. Marshall Stability, volumetric properties, resilient modulus, and dynamic creep test were performed to analyses asphalt mixture containing CCSA. It was observed that the addition of CCSA in asphaltic concrete gives the significant development in stability, modulus of resilient and creep stiffness. This study suggests that 4% and 6% of CBA as a supplementary binder could improve the mechanical properties of asphaltic concrete even under aging conditions.

1. Introduction

Coconut shell (CS) being hard and not easily degraded the material and bring the contribution to environmental pollution [1]. However, researchers in developing countries have found an alternative solution to reduce pollution by making sustainable use of waste. One of the common use of CS in the road industry is as aggregate replacement or filler in the binder [2]. The advantages of coconut shell are strong, rigid and lightweight material [3]. Also, it is very economical as large amounts are available as agricultural waste material. Furthermore, it is environmentally friendly because it is a natural material that is biodegradable and releases less of carbon dioxide when burned [4]. The utilisation of various agricultural waste materials in road construction has been carried for many years [5,6]. According to Slebi-Acevedo et al. [7], the use of various waste materials in the hot mix asphalt industry was due to concerns with the engineering, environment and economic factors. Agricultural wastes are lead to environmental problems. One solution is that these materials be recycled into useful materials; for example, by transforming them into modifying binder. Of all the agricultural wastes, coconut shell is seen as the material with the most potential to be produced as modify binder because of its strength and good quality in various construction materials [8]. Coconut shell has become a promising material that can be transformed into modifier due to its performance, environmental and economic advantages. Therefore, the potential of coconut shell for use as bitumen modifiers must be investigated in order to ensure the compatibility between the materials. Coconut consists of various components such as flesh, shell and fiber which can be recycled after the coconut water and flesh are taken [9]. Of the coconut components, coconut shell is mostly used both in the production of coconut-based products and in research areas. Based on past studies, coconut shell consists of three main compositions, which are hemicellulose, cellulose and lignin [10]. Study on coconut shell as bitumen modifier is very limited. For example, Buhari et al. [11] conducted research using coconut shell powder (CSP). The CSP was added at 2, 4, 6, 8 and 10% by weight of bitumen PEN 80/100. The results of the physical properties of the modified bitumen revealed that CSP improved the performance of the bitumen by decreasing the penetration and increasing the softening point, respectively. Another research that used a coconut shell as bitumen modifier was performed by Abdullah et al. [12]. Charcoal ash from coconut shell (CSC) at three different sizes was used to replace bitumen PEN 60/70 at 0, 10, 15 and 20%. The results showed that the penetration of the modified bitumen decreased while the softening point and viscosity increased up to 20% replacement. The results implied that the CSC improved the temperature susceptibility of the bitumen. Based on the past researches, it can be seen that coconut shell was most often used as filler in the construction materials. However, in bitumen modification is limited especially under aging session. Hence, the goal of this study is to determine the performance of asphaltic concrete incorporating charcoal coconut shell ash under short term aging.

2. Materials and Method

2.1. Binder

The binder used for this study is bitumen with the penetration grade 60/70. This bitumen was heated at 100°C for a period of 1 hour before being added to the aggregate mixes. The physical properties of 60/70 bitumen were 68 dmm penetrations (at 25°C) with a softening point approximately 52°C. In addition, the relative density of bitumen is 1.03 while the viscosity at a temperature of 135°C was 600cp.

2.2. Aggregate and gradation

In this investigation, crushed granite aggregates were used to prepare the asphalt mixture. While the asphaltic concrete grade 14 (AC14) was chosen for the mixture design based on the JKR specification [13]. The mix design incorporated a range of aggregate particle sizes, with each aggregate particle size in a given design mix contributing to the enhanced strength and durability characteristics of the asphalt structure. The combined gradation for each aggregate particle size (coarse aggregate, fine aggregate and mineral filler) for AC14 is presented in Table 1.

Table 1: Gradation limits of the combined aggregates for ACW14

Sieve size (mm)	Gradation (JKR, 2008)
20	100 – 100
14	100 – 90
10	86 – 76
5	62 – 50
3.35	54 – 40
1.18	34 – 18
0.425	24 – 12
0.15	14 – 6
0.075	8 – 4
Pan	-

2.3. Charcoal Coconut Shell Ash

At the laboratory, coconut shells were sun-dried to ease the removal of the coconut fibre. The shells were ripped out and washed out from any unwanted substances. Coconut shells were subjected under the heating process at 400°C to 450°C for five minutes using the furnace to change its properties to charcoal. The charcoal coconut shell was then left to cool down in room temperature before being crushed manually. Small sizes of crushed charcoal coconut shells were then were ground using Los Angeles Abrasion Value test (LAAV) with 1200 cycles until became ash in physically. CCSA was then sieved with the requirement of passing BS sieve 0.075mm. Charcoal coconut shell ash was then weighted in 2%, 4%, 6%, and 8% by the weight of bitumen for every each of testing conducted.

2.4. Marshall Stability Test

Marshall Stability test was used to determine the strength of an asphalt mixture that was compacted to a standard laboratory compaction effort. The Marshall Test procedure involved applying a compressive load to a cylindrical specimen with 101 mm diameter and 63.5 mm high. The temperature of the specimen was 60°C and the load applied was at a rate of 50 mm per minute. The test was carried out in compliance with ASTM D5581-07 [14].

2.5. Resilient Modulus Test

The 5-Pulse resilient modulus test was conducted in accordance with ASTM D7369-11 [15]. The specimens for this study were divided into two sets. Each set was conditioned at 25°C and 40°C correspondingly for 4 hours prior to testing. The resilient modulus value was calculated using Equation 1.

$$M_R = \frac{P}{Ht}(0.27 + \mu) \qquad (1)$$

Where **MR** is resilient modulus (MPa), **P** is applied force (N), **t** is thickness (m), **H** is horizontal displacement (m), and **μ** is Poisson ratio.

2.6. Dynamic Creep Test

Dynamic creep test was used to determine the rutting potential of asphaltic concrete. This test was carried out in accordance with BS EN 12697-25 [16]. Based on the standard, the specimen was conditioned at 40°C for at least 4 hours. The dynamic creep modulus was determined using Equation 2.

$$E = \frac{\sigma}{10 \times \varepsilon n} \qquad (2)$$

Where **E** is dynamic creep modulus (MPa); **Σ** is applied stress (kPa), and **ε** is measured vertical strain (mm).

2.7. Aging Test

Aging test was used to determine the deterioration of specimens. In this study, the aging procedure adopted was based on AASHTO R30-02 [17]. At the laboratory, the specimen was prepared under the same parameters as controlled mix up to the step of mixing. Then, these loose mixes were evenly placed in trays and arranged in a force draft oven at a temperature of 135±3°C for 4 hours and namely non-aging (NA). The force draft oven is used to simulate the hardening that binder would experience during seven to ten years of service. In short term aging (STA), the aging process ended with the removal of mixes from the oven after this period; then the loose mixes were compacted.

3. Results and Discussion

3.1. Stability

The stability of asphaltic concrete under NA and STA increases until a maximum at 4% CCSA content then reduces as the CCSA content increases as illustrated in Figure 1. In all cases, the stability of the asphaltic concrete increases with aging, the increase in stability partially due to the hardening of bitumen. Previously, Romastarika et al. [18] reported that the bitumen became harder after a certain aging condition. The results also indicate that the stability increases with increasing CCSA content up to a peak level and then decreases with further additions. For example, at the unaged condition, the stability value increases from 11,276 N to 13,532 N when the CCSA content increases from 0% to 4%.

Then start to decreases between 12,572 N to 12,170 N when the CCSA content increases from 6% to 8%. This means the addition of 2% CCSA to the asphaltic concrete mix can increase stability by up to 16.25%. Furthermore, the stability of specimens increased up to 14,818 N, and then relatively decreased between 14,591 N and 13,934 N after short term aging. The results show that the maximum stability at unaged is 13,532 N while under STA is 14,818 N, respectively. It can be seen that the addition of CCSA content is the main factor contributing mixes with higher stability.

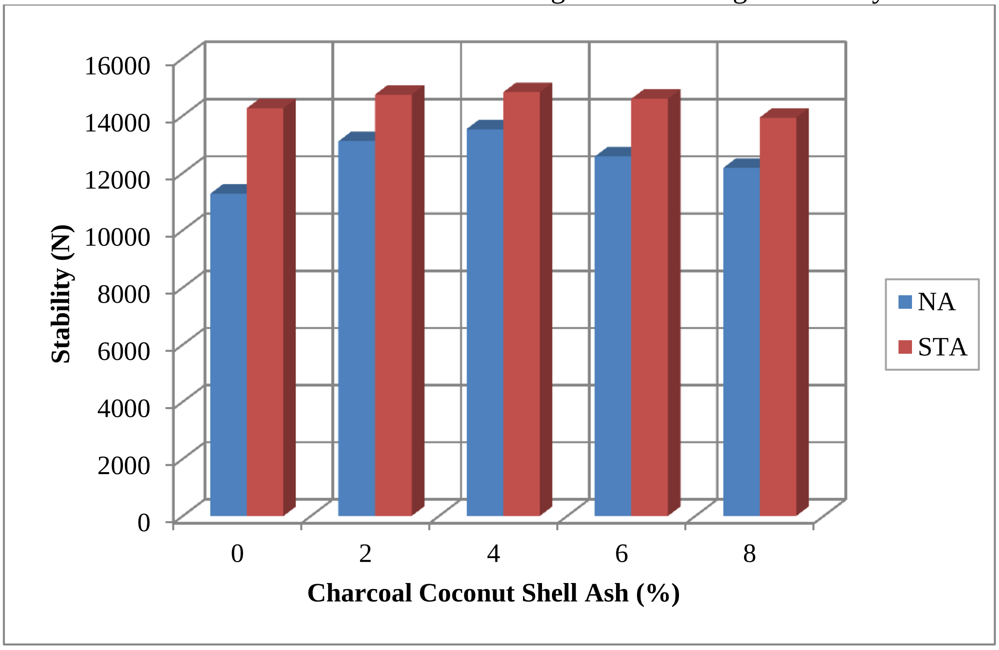

Figure 1. Stability of asphaltic concrete containing varying CCSA content

3.2. Stiffness

An overview of the stiffness results of CCSA asphalt mixture under NA and STA is graphically illustrated in Figure 2. In general, the stiffness value of specimens under STA is higher than those of NA due to hardening of the binder in CCSA mixture. For instance, at 0% CCSA, the stiffness of asphalt mixture increases by almost 4.3% after STA. The results also indicate that an increase in CCSA content causes the stiffness of the all mix types to increase until a maximum value is reached, beyond which the stiffness value decreases as the CCSA content continue to increase. For example, at the unaged condition, the stiffness of specimens with CCSA content increase by 8.7% after added 2% CCSA and, by 5.2% after STA. This showed that the aging process causes oxidation and increases the hardening rate of bitumen, thus resulting in increased stiffness. However, the different pattern is shown at 6% and 8% CCSA content where the stiffness of specimens decreases by 4.4% and 5.75, respectively.

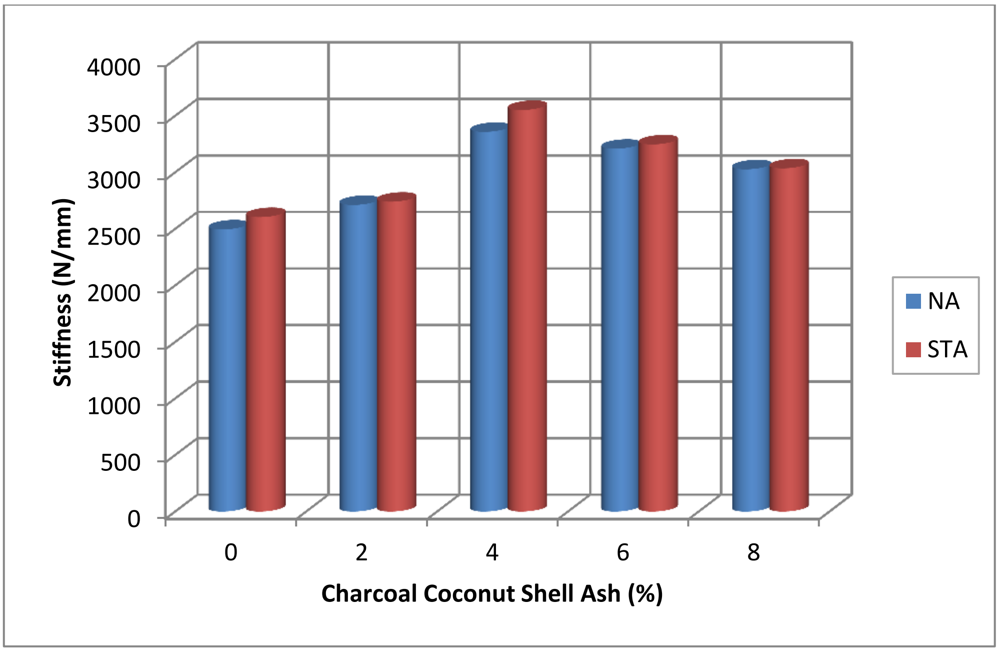

Figure 2. Stiffness of asphaltic concrete containing varying CCSA content

3.3. Flow

Curve illustrated in Figure 3 represent the relationship between the flow of asphalt mixed and CCSA contents under varying aging. In general, there were not many differences in flow observed from specimens subjected to NA and STA conditions. However, the flow values of all mix types were met all the requirements as specified by JKR standard for wearing course [13]. Based on Figure 3, the flow of asphaltic concrete initially increased during the CCSA content increases between 0 to 2% and then started to decrease until the specimens reached 8% CCSA. Asphaltic concrete incorporating 2% CCSA content exhibits a higher flow value compared to other mixture under both aging conditions. Previously, Wang et al. [19] reported that a modified mixture with waste material achieved the lowest flow when compared to the control mixture. The flow value represents the deformation rate potential in the asphalt mixture. High flow indicated that the high tendency in pavement mixture easily exposed the deformation.

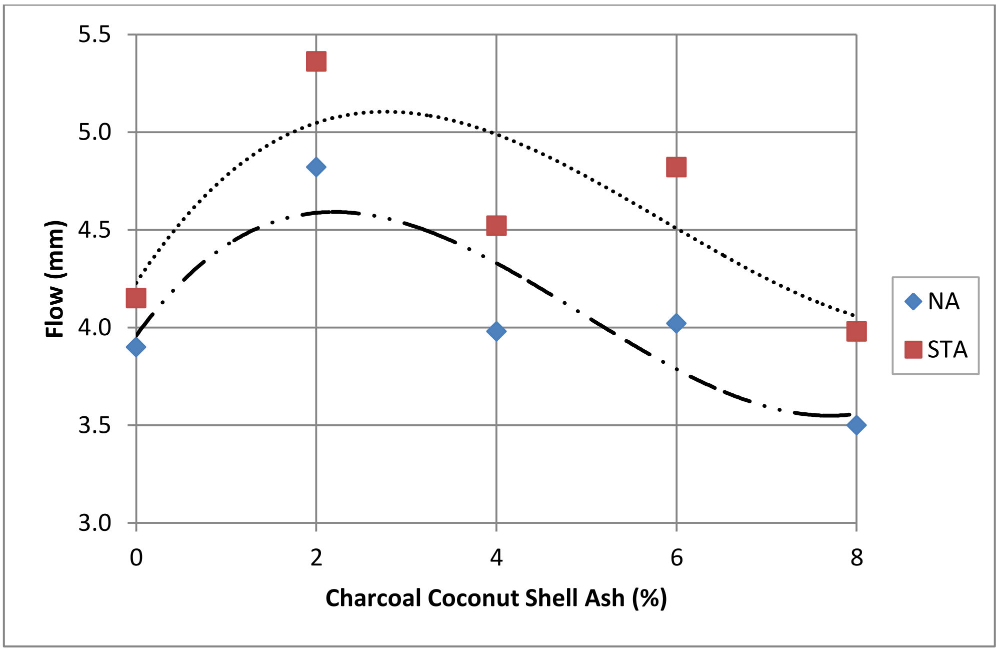

Figure 3. Flow of asphaltic concrete containing varying CCSA content

3.4. Voids in Total Mix

The voids in total mix versus CCSA content relationships of asphaltic concrete under different aging condition are presented in Figure 4. The results show that at the unaged condition, the VTM of 2% CCSA specimens are lower than the VTM of other mixture where the VTM of the controlled specimen under short term aging is less than that of other mixes. Lower air void contents minimize the aging of the asphalt cement films within the aggregate mass. Lower the air-voids as results less permeable of the mixture. However, higher air void content provides passageways through the mix for the entrance of damaging air and water. Test results also indicate that the VTM of the specimen under unaged increases between 2.5% to 3.7% when the CCSA content increases from 0% to 8% while the corresponding VTM under STA situation increases from 3.2% to 4.2%. This phenomena due to allowing more air voids in the specimens under NA compare to STA. On the other hand, poor air void contents minimize the possibility of moisture penetrating the thin asphalt cement film and strip the asphalt cement off the aggregates.

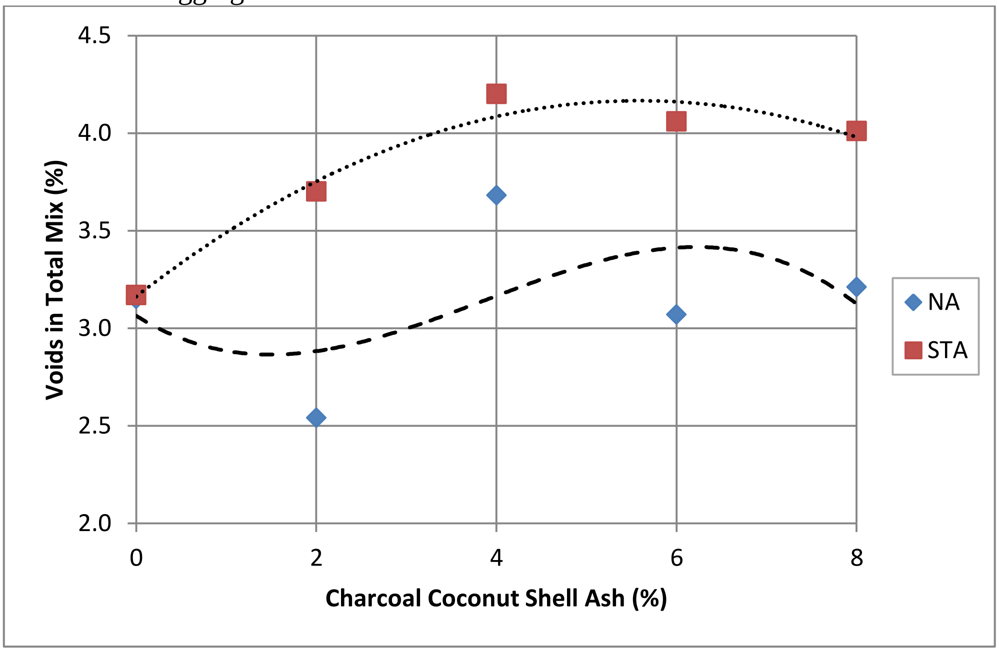

Figure 4. VTM of asphaltic concrete containing varying CCSA content

3.5. Voids Filled with Bitumen

VFB represents the number of voids which are filled with a binder in an asphalt mixture. As shown in Figure 5, the VFB of asphaltic concrete specimens increases from 39% to 96% and 36% to 95% when the CCSA content increases from 0% to 8%, respectively for NA and STA. The VFB of specimens peaks at the CCSA content of 8%. At all aging session, the minimum VFB value of mixes is 36% (0% CCSA) content while the maximum VFB value is 96% (8% CCSA). According to JKR specification [13] for dense mixes, the VFB should range from 75% to 85%. However, the specification does not specify limitation values for dense asphalt mixture, especially for incorporated with waste agriculture product.

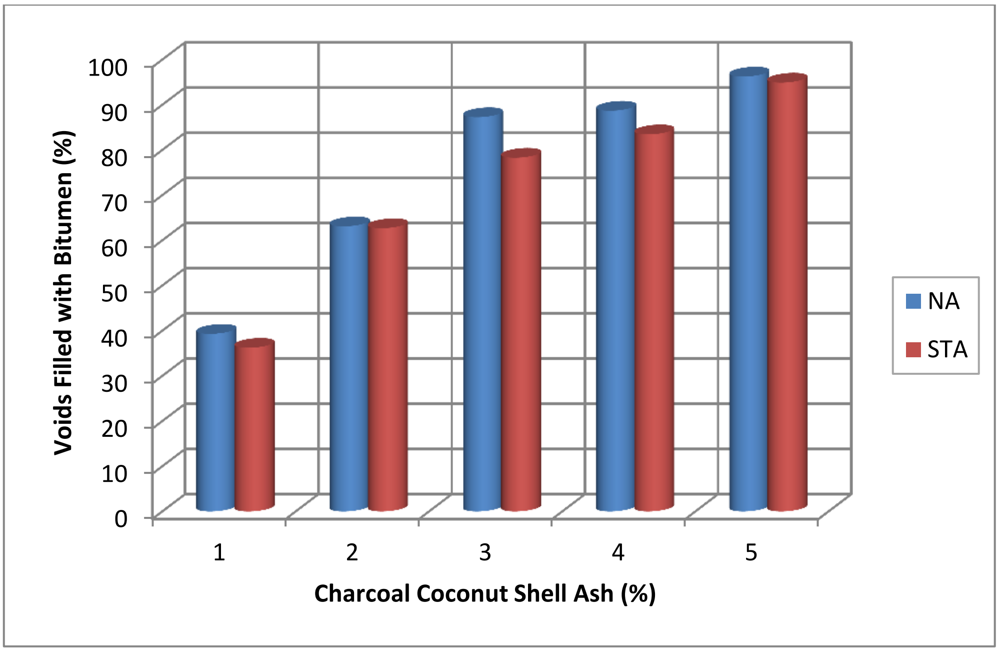

Figure 5. VFB of asphaltic concrete containing varying CCSA content

3.6. Resilient Modulus

The results of the resilient modulus test for aged specimens at varying CCSA content and temperature are graphically illustrated in Figure 6. Generally, the results indicate that an increase in CCSA content causes the resilient modulus of the mix to increase until a maximum value is reached, beyond which the resilient modulus decreases as the CCSA content continue to increase. At all conditions, the resilient modulus increases with increasing CCSA content up to a 6%, then start to decreases with further additions of CCSA. In addition, the resilient modulus of specimens increases after every aging session. For example, at 2% CCSA, the resilient modulus at the temperature of 25°C increases by 10.8% after STA and 85% when exposed under 40°C. It can be seen that the aging process causes oxidation and increases the hardening rate of the bitumen, thus resulting in the increasing resilient modulus. This phenomenon is usually termed as age hardening [20]. Furthermore, the resilient modulus of aged specimens also reduces when the temperature increases. The resilient modulus of unaged at 6% CCSA is higher than the resilient modulus of 0%, 2%, 4% and 8% CCSA at every test temperature. However, at STA session, 4% CCSA is higher than other mixtures.

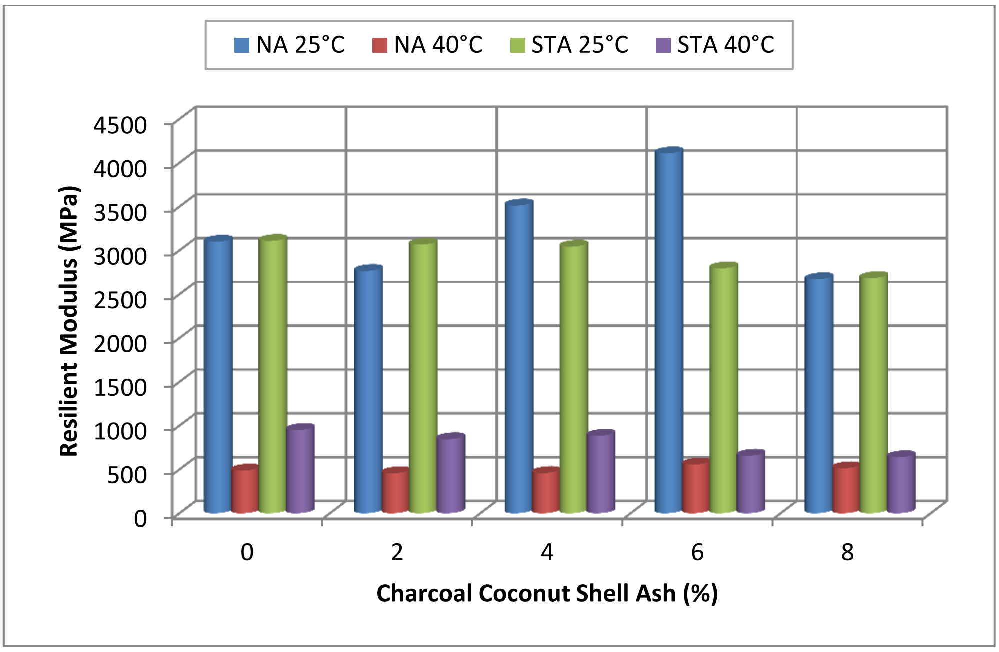

Figure 6. Resilient Modulus of asphaltic concrete containing varying CCSA content

3.7. Dynamic creep

Creep modulus from the dynamic creep test on aged specimens was used to predict the ability of mixes containing CCSA to resist permanent deformation after 10 to 15 years' service period. In this study, the dynamic creep test was determined after 3600 load cycles, and the test results are illustrated in Figure 7. The test results indicate that the creep modulus of specimens at unaged condition increases up to a distinct peak beyond which the creep modulus reduces as the CCSA content increases. The creep modulus under STA exhibits similar trend peaks at different CCSA content. The creep modulus of aged CCSA asphalt mixes is generally higher than unaged mixes. The test results also show that aging causes creep modulus of CCSA asphalt mixes to exhibit higher resistant against rutting. Age hardening of the binder causes an increment of approximately 10% in creep modulus after short term aging.

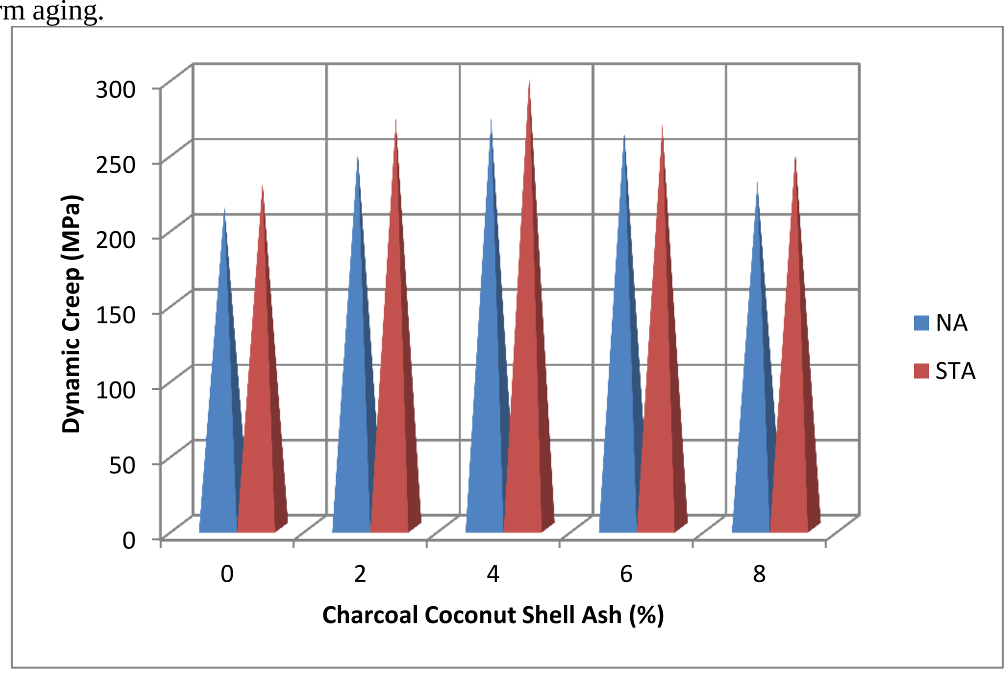

Figure 7. Creep modulus of asphaltic concrete containing varying CCSA content

4. Conclusions

Following conclusions could be drawn from the experimental study:

a) This study indicated the potentiality of charcoal coconut shell ash (CCSA) as modify binder in hot mix asphalt.
b) The addition of charcoal coconut shell ash as binder replacement improved the stability, stiffness, resilient modulus and dynamic creep of the asphalt mixture.
c) Asphalt mixture incorporating charcoal coconut shell ash exhibits higher performance after short term aging session.

5. References

[1] Lay Ting T, Putra Jaya R, Abdul Hassan N, Yaacob H and Sri Jayanti D 2015 *J. Teknologi*. **76**(14) pp. 121-125
[2] Jeffry S N A, Jaya R P, Manap N, Miron N A and Hassan N A 2016 *Key Eng. Mater.* **700** pp. 227-237.
[3] Ramadhansyah P J, Nurfatin Aqeela M, Siti Nur Amiera J, Norhafizah M, Norhidayah A H and Dewi S J 2016 *ARPN J. Eng. Appl. Sci.* **11**(12) pp. 7457-7462.
[4] Chen H and Xu Q 2010 *Fuel.* **89**(7) pp. 1616-1622.
[5] Yin J M and Wu W 2018 *Waste Manage*. **78** pp. 948-954.
[6] Liu X and Wu S 2011 *Constr. Build. Mater*. **25** pp. 1807-1811.
[7] Carlos J. S-A, Pedro L-G, Pablo P-M and Daniel C-F 2019 *Constr. Build. Mater*. **200** pp. 756-769.
[8] Norhafizah M, Ramadhansyah P J, Siti Nur Amiera J, Nurfatin Aqeela M, Norhidayah A H, Hainin M R and Che Norazman C W 2016 *J. Teknologi*. **78**(7-2) pp. 127-132.
[9] Abiola O S, Kupolati W K, Sadiku E R and Ndambuki J M 2014 *Constr. Build. Mater.* **54** pp. 305-312.
[10] Jeffry S N A, Jaya R P, Abdul Hassan N, Yaacob H and Satar M K I M 2018 *Constr. Build. Mater*. **173** pp. 40-48.
[11] Buhari R, Nur Fareesya Z, Mohd Ezree A, Siti Khatijah A B and Nurul Hidayah M K 2016 *J. Teknologi* **78**(7–3) pp. 17–22.
[12] Abdullah M E, Rosni N N M, Jaya R P, Yaacob H, Hassan N A and Agussabti 2017 *Key Eng. Mater.* **744** pp. 121-125
[13] Jabatan Kerja Raya Malaysia 2008 *Standard Specification for Road Works – Section 4*: *Flexible Pavement*. Kuala Lumpur, Malaysia.
[14] ASTM D5581 2007 *Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus*. ASTM International, West Conshohocken, PA, USA.
[15] ASTM D7369 2011 *Standard Test Method For Determining The Resilient Modulus Of Bituminous Mixtures By Indirect Tension Test*. ASTM International, West Conshohocken, PA, USA.
[16] BS EN 12697-25 2016 *Bituminous mixtures. Test methods. Cyclic compression test.* British Standards Institution, UK.
[17] AASHTO R30 2002 *Mixture Conditioning of Hot Mix Asphalt (HMA)*. American Association of State Highway and Transportation Officials, Washington D.C, USA.
[18] Romastarika R, Jaya R P, Yaacob H, Nazri F M, Agussabti, Ichwana and Jayanti D S 2017 *AIP Conf. Proc.* **1875** pp. 1–8.
[19] Wang H, Shihao Z, Guojun L and Junwei X 2019 *Constr. Build. Mater*. **226** pp. 442-448.
[20] Ting T L, Ramadhansyah P J, Norhidayah A H, Yaacob H, Hainin M R, Wan Ibrahim M H, Jayanti D S and Abdullahi A M 2018 *IOP Conf. Ser.: Mater. Sci. Eng*. **140**(1) pp. 1-8.

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