

# RHEOLOGICAL BEHAVIOUR OF COCONUT SHELL POWDER MODIFIED ASPHALT BINDER

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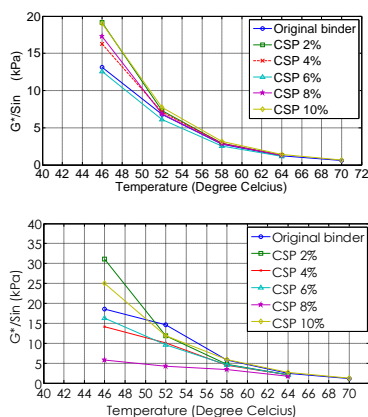
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## Graphical abstract



## Abstract

The objectives of this study were to determine the blending parameters of coconut shell powder (CSP) modified asphalt binder and to evaluate the rheological properties of CSP modified asphalt binder. CSP of 2%, 4%, 6%, 8% and 10% by weight of asphalt have been incorporated into an unaged 80/100 asphalt mix in order to improve its performance. The influence of the additives on the physical and rheological properties was evaluated with penetration test, softening point, storage stability, dynamic shear rheometer test (DSR), and Field Emission Scanning Electron Microscope (FESEM). The aging of asphalt binders was simulated in a laboratory by using Rotational Thin Film Oven (RTFO). The results showed that the addition of CSP into virgin binder was decreasing the penetration value and increasing the softening point temperature compared to the original binder. On the rheological effect, for unaged modified binder, higher CSP resulted higher  $G'/\sin \delta$  especially at lower temperature compared to the unaged control binder. Besides, for the aged modified binder, stiffness was lower than the control aged binder for all temperature.

Keywords: Coconut shell powder, asphalt aged, rheology, morphology, stiffness.

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## 1.0 INTRODUCTION

In recent years, with the continuously increasing traffic volumes and heavy loads, control binders were found not to perform satisfactorily under some crucial conditions [1]. That included the response given by the vehicles which were achieved more than 3 times of its static load due to the road condition and/or the overloading [2-3].

In addition, unpredictable weather factors can also weakened the pavement capabilities. Climatic conditions which are experiencing rain and heat throughout the year has always been a major contributor to the failure of roads and causing danger to the road users. In order to improve the quality of human life, an effort is needed to be efficiently

implemented in the planning decision, design making, constructions operation and maintenance phases. The most significant approach is by modifying the asphalt towards stiffening of the asphaltic pavement.

Asphalt which is used widely in Malaysia is the result of agro-petroleum distillation process of crude oil. Aging of asphalt can occur during storage, mixing, transporting and putting it on the road, arising so many problems during the process of constructions and making it somehow difficult [4]. In the increasing use of modified asphalt binders, there is a great need for methods that can evaluate the effectiveness of these modifiers, including the variables such as modifier content and composition of the base asphalt and for some specifications that are applicable to these materials [5]. One of the additives is CSP. Several other

usage of CSP includes; as a raw material for activated carbon industries, as a filler for synthetic resin glues, as specialized surface finishing liquid products (as an absorbent), mastic adhesives, resin casting and bituminous products, as a smooth and lustrous finish to moulded articles, and also as an agent to improve their resistance to moisture and heat, used as a mild abrasive in shot blasting of delicate objects and of historic buildings etc.

The coconut shell can be processed into CSP and utilized as functional filler in plastics such as polypropylene to increase their stiffness. The CSP is eight times as hard as polypropylene and can easily double the stiffness of polypropylene. It can be used in applications of which consumer goods is manufactured using injection moulding, extrusion, or thermal forming [6]. The use of this agricultural waste in asphalt binder as additive can reduce cost and improve mechanical properties of the composite material. Recycling of the disposed material is one method of treating the agricultural waste and also produces of an exceptionally high performance of a new pavement [7].

This research was conducted to evaluate the feasibility of using CSP to extend the service life of a pavement binder.

## 2.0 EXPERIMENTAL DESIGN

### 2.1 CPS Production

The coconut shell waste was obtained to produce CSP by using milling machine at polymer and ceramic laboratory in the Faculty of Mechanical and Manufacturing Engineering (FKMP), UTHM. Figure 1 shows a production of CSP from coconut shell. The left and right parts of the figure are the coconut shell sizes throughout the process and the machines that were used respectively.

Before milling, the process started with breaking down shells into small pieces (5mm) with plastic granulator machine. Other machine was then used to break down the shells again into smallest particle possible of 2mm in dimension. The ground shell powder was then fed into the rotor mill machine to obtain finest particle of about 200  $\mu\text{m}$ . Finally the ground CSP was sieved out using automatic sieve shaker to obtain powder of required mesh which is 90  $\mu\text{m}$ .

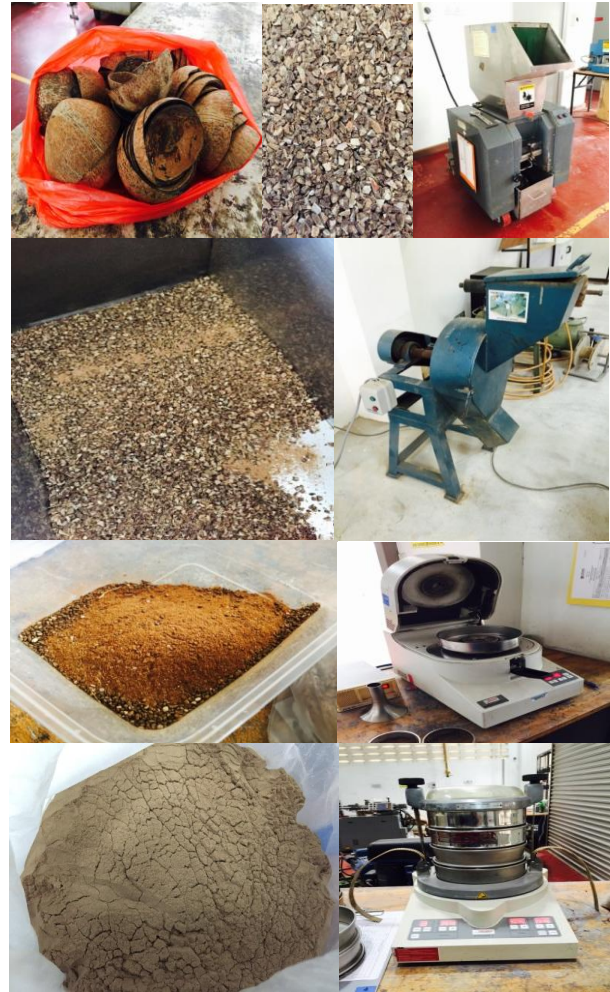


Figure 1 Production of Coconut shell powder

### 2.1 Sample Preparation

The material used in this study was asphalt penetration grade 80/100 from Chevron. The properties of the virgin binder (control binder) are shown in Table 1. There are two sets of binder which were produced, the unaged and aged binder. Each set has control and modified binder (contained 2%, 4%, 6%, 8% and 10% of CSP from the total weight of total binder). For the modified binder, 500 g of virgin binder was mixed with CSP with a mixing speed of 3000 rpm, for 1 hour at 175°C [8]. In order to conduct the mixing, 500g of oven heated asphalt was transferred to a hot plate and after the temperature of the sample stabilized at 175°C, the specific amount of CSP was added gradually into the asphalt as the high shear asphalt mixer was rotating at specified speed for 1 hour until it reached homogenous blend.

**Table 1** Asphalt properties

Properties	Results	Penetration Grades 80/100	
		Min	Max
Penetration at 25°C (dmm) MS 124:1996	81	80	100
Softening point, (°C) MS 687:1995	46	45	52

### 2.3 Binder Aging Conditions

A CSP modified binder samples were subjected to short-term aging by artificially conditioning the samples in the laboratory via the rolling thin-film oven (RTFO) according to ASTM D2872 [9] procedures. Based on the procedure, the artificially conditioning 35 g of binder sample was placed in a glass bottle with a narrow top opening. The glass bottles opening were facing an air jet in the 163°C oven while rotating at 15 rpm for 85 minutes. Subsequently, samples were removed and poured into small containers for further tests.

### 2.4 Penetration Test

The penetration test provided a measure of the consistency or hardness of the asphalt. In this test, a specified needle was allowed to penetrate a binder sample, under a 100 g load at 25°C temperature for 5 seconds as outlined in ASTM D5 [10] procedures.

### 2.5 Softening Point Test

The softening point test is defined as the mean temperature at which the asphalt disk softens and sags downwards a distance of 25 mm under the weight of a standard 3.5 g steel ball. The water bath temperature was raised at 5°C per minute. The asphalt then softened and eventually deformed slowly with the ball moving through the ring. The temperature was recorded when the ball touched the bottom plate. This temperature was designated as the softening point of the asphalt and represents an equi-viscous temperature. The test was carried out in accordance with ASTM D36 [11] procedures.

### 2.6 Storage Stability Test

Hot storage test was conducted to evaluate the high temperature storage stability of the modified asphalt. An aluminium tube (25 mm in diameter and 140 mm in height) was filled with about 50 g. Then, sample was maintained in a vertical vessel at  $163 \pm 5^\circ\text{C}$  for  $48 \pm 1$  hour. After that, it was removed and cooled in a freezer of  $-6.7 \pm 5^\circ\text{C}$  for a minimum of 4 hours to ensure the sample has completely become solid. Finally, the

tube was cut into three equal sections. The two ends (top and bottom) were analysed further according to the ring and ball softening point test (ASTM D36), to evaluate possible differences in the characteristic. If the difference between softening point of the top and bottom sections of the tube is less than 2.5°C, the sample could be regarded as storage stable blend which is a very important parameter of initial properties on modified asphalt binder (ASTM D5926).

### 2.7 Observing of Microstructure

FESEM is a test to provide topographical and elemental information at magnifications of 10x to 300,000x with virtually unlimited depth of field. It is also a very useful tool for high resolution surface imaging in the fields of micro and nano materials science. The compatibility between control binder and additive is critical to the properties. The morphology of the CSP and CSP modified asphalt binder was investigated using FESEM by characterizing the distribution and the fineness of binder matrix.

### 2.8 Dynamic Shear Rheometer Test

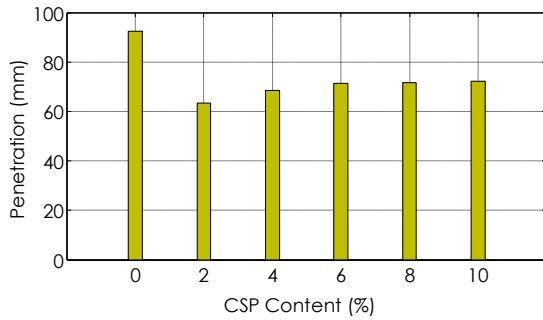
The Dynamic Shear Rheometer (DSR) test was conducted in accordance with Superpave™ [12] requirements to characterize asphalt binder rheology and elastic behaviour by measuring the complex modulus ( $G^*$ ) and phase angle ( $\delta$ ) of the asphalt binder at different temperatures. The complex shear modulus ( $G^*$ ) is one of the most important rheological characteristics of viscoelastic materials. In this study, the effects of CSP content on the rheological characteristics of unaged and short-term aged binder samples at intermediate temperatures were investigated in terms of complex shear modulus ( $G^*$ ) and the phase angle ( $\delta$ ) determined from the DSR test. Temperature sweeps were applied from 46°C to 82°C at 6°C increments for the unaged and short-term aged samples. The samples diameter and thickness were 25mm and 1mm, respectively. The loading frequency sweep was 1.59 Hz or 10 rad/s.

## 3.0 RESULTS AND DISCUSSION

### 3.1 Penetration

Figure 2 shows the average penetration value from 6 samples reading. It showed that the penetration was decreases as the percentage of additive was added to the binder especially at 2% CSP. The addition of CSP into virgin binder has shown satisfying result in decreasing the penetration value compared to the original binder. However, by increasing the CSP, the penetration was increased but still lower than the control binder. Then, as it reached the concentration of

6%, the penetration values started to go constant until it reached the concentration of 10%.



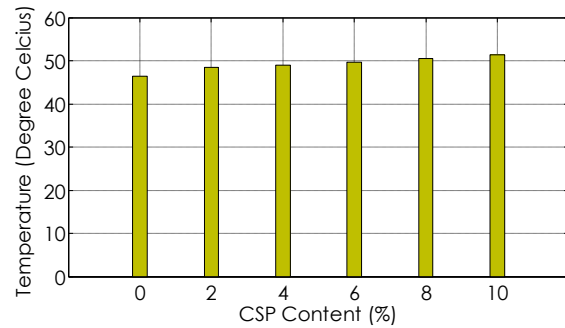
**Figure 2** The penetration for unaged control and modified binder as increase in percentage of CSP

### 3.2 Softening Point

Figure 3 shows the softening point values of virgin and modified binder for the unaged samples. The overall softening points for the various concentration of CSP modified asphalt were in a small range which indicated that CSP has little impact in rising the softening point. The results indicated that the softening point for unaged samples were increased as the percentage of CSP increased. It is clearly seen that the 10% of CSP unaged modified binder softening point is the highest compared with the unaged control binder. In general, the increasing values of softening of CSP modified binder demonstrate the increased hardness of the binder which is desirable in asphalt industry.

### 3.3 Mass Loss

Mass loss was determined to measure the effect of heat and air on a moving film of semisolid asphalt binder. The amount of volatile loss during short term ageing (at 163°C for 85 minutes) is an indication of the amount of aging that may occur in the asphalt during mixing and construction operations. As seen in Table 2, the percentages of mass loss for all modified binder are less than 1% thus they fulfill the requirement. The result shows the values in the range of 0.08% to 0.89% which satisfied the standard specification. Thus, by increasing the percentage of CSP modified binder, it increased the mass loss value.



**Figure 3** The softening point for unaged control and modified binder as increase in percentage of CSP

**Table 2** Result shows the mass loss in aging

Binder	Average Mass Loss (%)
Virgin asphalt binder	0.08
2% CSP	0.09
4% CSP	0.18
6% CSP	0.22
8% CSP	0.64
10% CSP	0.89

### 3.4 Storage Stability

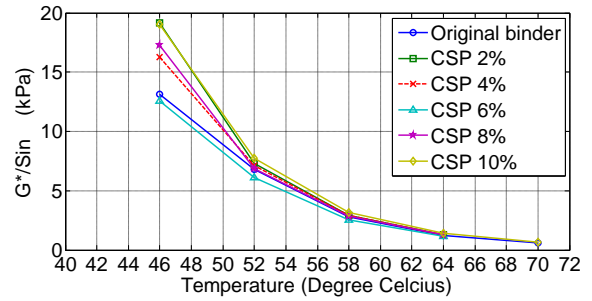
The storage stability of bituminous binder was observed in terms of difference in softening point of sample from upper portion and lower portion. Softening point test is a medium to find out whether interaction between the control binder with the increasing percentage of CSP is strong enough to resist separation during the high temperature storage stability test. Temperature difference of modified asphalt binder was less than 2.5°C. Table 3 shows the results for this test. Based on the results, it showed that the difference in temperature of unaged sample was less than 2.5°C, therefore it is proven that the mixture was homogeneously mixed and it has good storage stability.

### 3.5 Analysis of Microstructure

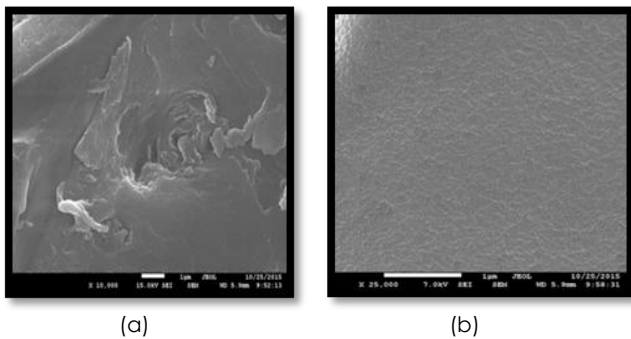
The morphology of the CSP modified binder was examined using FESEM by characterizing the distribution and the fineness of CSP in binder matrix. More focus was given towards the homogeneity in the blending of asphalt. Figure 4(a) shows FESEM images of CSP micro particles and Figure 4 (b) proves that the virgin binder and CSP were homogeneously mixed.

**Table 3** Storage stability test results of unaged modified binder

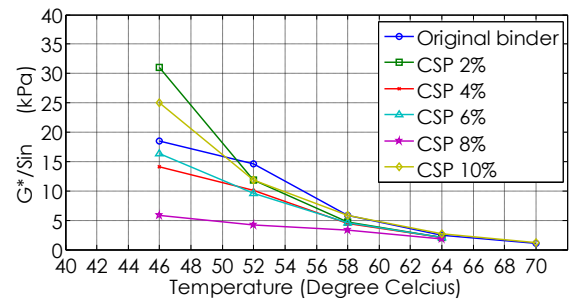
Specimen	Results (°C)	
	Averages	Differences between top and bottom
CSP2	Top	54.6
	Bottom	52.4
CSP4	Top	52.8
	Bottom	52.2
CSP6	Top	55.9
	Bottom	53.6
CSP8	Top	52.6
	Bottom	52.9
CSP10	Top	55.2
	Bottom	55.0



**Figure 5**  $G^*/\sin \delta$  against temperature of unaged Control and modified binder containing different percentage of CSP



**Figure 4** Example of the FESEM output; (a) FESEM images of CSP micro particles; (b) FESEM image of 4% CSP micro particles and the modified binder is homogeneously mixed



**Figure 6**  $G^*/\sin \delta$  against temperature of aged control and modified binder containing different percentage of CSP

**3.6 Complex Modulus**

As seen in Figure 5, all of the unaged and aged of unmodified and modified binder was tested at a starting temperature of 46°C and continued until it reached a fail temperature. A factor of  $G^*/\sin \delta$  value less than 1.0 kPa for an unaged binder and 2.2 kPa for aged binder often used to determine the performance grade of an asphalt binder [13-14]. The effect of different percentages of CSP on  $G^*/\sin \delta$  with the temperature is presented in Figure 5 or 6. Although the percentage of CSP result was higher,  $G^*/\sin \delta$  was higher especially at the lower temperature. Even though the  $G^*/\sin \delta$  was rapidly decreasing from 46°C to 52°C and about the same height as the temperature was increasing. The same pattern is shown for the aged binder as seen in Figure 6. The  $G^*/\sin \delta$  decreased as the temperature increased. Although for the modified binder, the stiffness is lower than the control aged binder for all temperature.

The  $G^*/\sin \delta$  values for unaged modified binder prepared using CSP contents and the aged control binder tested at 46°C and 70°C, were found in the range of between 19.18 kPa to 0.550 kPa and 13.14 kPa to 0.569 kPa, respectively. The  $G^*/\sin \delta$  values for aged modified binder prepared using CSP contents and the aged control binder tested at 46°C and 64°C, were found ranged between 31.08 kPa to 1.771 kPa and 18.53 kPa to 1.10 kPa, respectively.

**4.0 CONCLUSION**

As mentioned earlier the aim of this study was to determine the possibility and the effects of using CSP as a binder additive. The following conclusions from the findings can be drawn as:

- i. The CSP modified asphalt binder is found to satisfy the physical property requirements. Results of the penetration test showed that 2% of CSP of the unaged modified binder with lower value of penetration indicated that the stiffness of the binder is improved. Results of the softening point test showed, the 10% of CSP of the unaged modified binder with highest value of softening point has given the asphalt mixtures more

resistance against the permanent deformation at high temperatures. Based on the storage stability result, it is clearly shown that the difference in temperature of the unaged sample is less than 2.5°C, therefore it has proven that the mixture was homogeneously mixed and has good storage stability.

- ii. The FESEM result shows homogeneity of CSP in the asphalt matrix, the blends of concentration of CSP were 0%, 2%, 4%, 6%, 8% and 10% were mixed with the weight of asphalt binder at a temperature controller of 175°C and 3000 rpm for 1 hour.
- iii. The unaged and aged of the control and modified binder showed an increase in the  $G^*/\sin \delta$  parameter in the test at 64°C, meaning that this modified asphalt is better in rutting resistance compared with the virgin binder.
- iv. A modified binder contains of 10% of CSP shows better performance in penetration, softening point and complex modulus tests compared to others.
- v. The results of the analysis showed the successful application of CSP as an additive agent for binder. This application is able to be introduced as an environmental and economical solution for the reuse of this waste material but with an appropriate range.

### Acknowledgement

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