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# USE OF COCONUT SHELL FROM AGRICULTURE WASTE AS FINE AGGREGATE IN ASPHALTIC CONCRETE

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## ABSTRACT

This study was carried out to evaluate the performance of coconut shell as fine aggregate in asphaltic concrete. The mix design incorporating penetration grade 80/100 bitumen was used to produce the specimens testing. Four coconut shell replacement levels were considered in the study: 10%, 20%, 30%, and 40%, respectively. The aggregate properties were evaluated through aggregate impact value, specific gravity and water absorption test. In addition, the performance of coconut shell in asphalt mixes was identified by volumetric properties, indirect tensile strength, resilient modulus and dynamic creep test. The results revealed that controlled specimen's shows better volumetric properties compared to coconut shell mixes. However, 10% replacement of coconut shell indicated better performance than controlled specimen. It can be concluded that coconut shell inhibits great potential as road construction material but be only suitable for low traffic volume and at rural area.

**Keywords:** coconut shell, bitumen, modulus stiffness, creep stiffness, aggregate.

## INTRODUCTION

Modern hot mix asphalt is using different size distribution (gradation) aggregate stockpiles which are introduced into the plant through a set of feed bins or directly fed from the stockpiles; bleeding and drying in a drum dryer and blending the hot aggregates with asphalt and storing in insulated silos for use in pavement construction. The strength is resulted from the interlocks between the aggregate and assist to distribute loads from the traffic in the pavement. Aggregates are the main material that makes up about 93% of the mix [1].

Nowadays, there are many researches that have been done to improve and upgrading the materials for preparing hot mix asphalt [2, 3, 4]. The utilization of waste material as a replacement for producing hot mix asphalt can give a lot of benefit to the humans [5]. Coconut shell is a one of the alternative that can be used to replace aggregate in preparing a flexible pavement. Coconut is grown in more than 93 countries. South East Asia is regarded as the origin of coconut [7]. Coconut Shell, which presents serious disposal problems for local environment, is an abundantly available agricultural waste from local coconut industries.

In developing countries where abundant agricultural and industrial wastes are discharged, these wastes can be used as potential replacement material in the construction industry. This will have the double advantage of reduction in the cost of construction material and also as a means of disposal of wastes. According to [7], coconut shell is compatible and no pre-treatment is required. Coconut shells are not commonly used in the construction industry but coconut shells were more suitable as low strength-giving lightweight aggregate when used to replace common coarse aggregate in concrete production.

Many researchers have investigated this matter in various part of building for example; [8] investigate the behavior of reinforced concrete beams with coconut shell as coarse aggregates. He found that, the overall flexural behaviors of reinforced beam with coconut shell are closely equivalent with using natural aggregates. [9] have studied the properties of concrete that using coconut shell as coarse aggregate and the result is the compressive strength is decrease as the percentage of coconut shell increase. Coconut shells also have been used since long ago to build the house [10]. Besides, coconut shells also being used on ceramic and mosaic production, bird house, ceiling and wall [11]. These facts show that the demand of the natural aggregate is very high. Therefore, coconut shell can be used to replace natural aggregate in the road construction of wearing course. It is one way to sustain our environment and world.

## MATERIALS AND EXPERIMENTAL PROCEDURES

### Raw materials preparation

The binder used for this study is bitumen with the penetration grade 80/100. This bitumen was heated at 100 °C for a period of 1 hour before being added to the aggregate mixes. On the other hand, two aggregate types were used in this research such as granite and coconut shell. Granite is nearly always massive (lacking internal structures), hard and tough, and therefore it has gained widespread use as a construction [12]. In this investigation, the coconut shells were obtained already crack in 50 to 100 millimeters but the fibre and coconut meat still there. They were sun dried for 24 hours before the fibre were removed. The fibres were removed using cutter. Some of the shells are being crushed manually by using pestle and mortar. Then, other shells are being crushed using aggregate crushing machine. The coconut shells are sieved according to the specification [13] as

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shown in Figure-1. Table-1 provides a guide on mix designation.

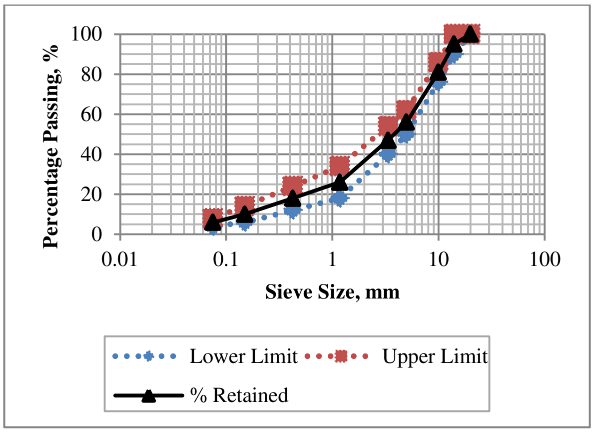


**Figure-1.** Gradation limit for asphaltic concrete (JKR, 2008).

**Table-1.** Mix Designation of Specimens.

| Mix design | Coconut shell (%) | Designation |
|---|---|---|
| Asphaltic Concrete | 0 | AC-CS0 |
| | 10 | AC-CS10 |
| | 20 | AC-CS20 |
| | 30 | AC-CS30 |
| | 40 | AC-CS40 |

**Aggregate impact value**

The aggregate with size passing 14mm and retained on 10mm was used. Aggregate was placed in the mould and compacted with 25 time rodding. The specimen is subjected to 15 times impacts from a dropping weight. This action will break the aggregate to a degree which is dependent on the impact resistance of the material. This degree was assessed by sieve analysis test on the impact specimen using 2.36mm sieve size and it is taking as aggregate impact value (AIV). The test was carried out in accordance with BS EN 1097-2:2010.

Specific Gravity and Water Absorption

The specific gravity or relative density and water absorption tests were done to determine the physical characteristics of the aggregate used. The specific gravity were measured on the basis of oven dried, saturated surface-dried and apparent. All specific gravity tests were carried out in accordance with ASTM C 127-12.

**Volumetric properties test**

The void in total mix (VTM) and void filled with bitumen (VFB) were examined as volumetric properties. VTM is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the compacted mixture). VFB is the percent of the volume of the VMA that filled with bitumen. The test was carried out in accordance with ASTM D 6927-06.

**Indirect tensile strength test**

The indirect tensile strength of bituminous mixtures is conducted by loading a cylindrical specimen across its vertical diametral plane at a specified rate of deformation and at 25 ˚C temperature. The peak load at failure is recorded and used to calculate the IDT strength of the specimen as Equation 1. The test was carried out according to the ASTM test method D 6931-12 ASTM, 2012).

$$S_t = \frac{2000\,P}{\pi\, t\, D} \quad (1)$$

St = IDT strength (kPa)
P =Maximum load (N)
t =Specimen height before test (mm)
D = Specimen diameter (mm)

**Resilient modulus test**

Resilient modulus test is to determine resilient modulus values using the repeated load indirect tension. Resilient modulus sample will be testing at two temperatures which are 25°C and 40°C. The specimen was adjusted to sit in the centered position of the testing rig. Adjustments were made at the horizontal strain detector by referring to an electronic measuring system in the computer. The test was started when the position of sample and strain detector was well positioned. This test was repeated on the same specimen but rotated through 90°. The test was carried out in accordance with ASTM D 4123-82. The resilient modulus value of a sample was calculated using Equation 2.

$$M_R = \frac{P}{Ht}(0.27 + \mu) \quad (2)$$

MR = Resilient modulus (MPa)
P = Applied force (N)
t = Sample thickness (m)
H = Horizontal displacement (m)
µ = Poisson ratio

**Dynamic creep test**

Dynamic creep test is an indirect tensile test and the simplest method of assessing the resistance to permanent deformation or rutting. The test will be start by placing the specimen in a controlled temperature chamber maintained at test temperature of 40 °C for three hours. Adjustments to the vertical leveling sensor to ensure the readings of the deformation started from origin. Then repeated load will be applied for 3600 cycles for 30 minutes. The test was carried out in accordance with BS EN 12697-25: 2005. The dynamic creep modulus was determined using Equation 3.

$$E = \frac{\sigma}{\varepsilon} \quad (3)$$

E = Dynamic creep modulus (MPa)
Σ = Applied stress (psi)
Ɛ = Measured vertical strain (mm)

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## RESULTS AND DISCUSSIONS

### Aggregate properties

Based on Table-2, coconut shell has more strength on aggregate impact value which only 5.7% and has low effect on impaction compared to natural aggregates. It shows that coconut shell has ability to resist sudden shock or impact. [14] also agree with coconut shell exhibits more resistance against crushing impact. Natural aggregates' value on AIV is close to maximum specification which is 28.2%. Coconut shell is lower than natural aggregates in specific gravity for both coarse and fine aggregates. It also same with water absorption (WA) where the percentage of WA for coconut shell is higher than natural aggregates. Therefore, the ability of coconut shell to absorb bitumen during mixing is higher. [15] Found that specific gravity of coconut shell is about 1.33 and water absorption is 8%. It shows the specific gravity for coconut shell did not have much different but seem that [16] found better coconut shell on water absorption. While [17] found that water absorption for coconut shell is 24%. This value is not much different from the result in this study.

**Table-2.** Aggregates properties results.

| Properties | Coconut shell | Natural aggregates |
|---|---|---|
| Aggregate Impact Value | 5.7 % | 28.2 % |
| Specific Gravity (Coarse) | 1.467 | 2.653 |
| Specific Gravity (Fine) | 1.439 | 2.484 |
| Water Absorption (Coarse) | 29.31% | 0.54% |
| Water Absorption (Fine) | 14.51% | 1.78% |

### Mix density

The densities of asphaltic concrete at different percentage coconut shell are presented in Figure-2. Generally, the densities of specimens are decrease by increasing coconut shell. The rate of decrease in density with respect to coconut shell content of all mixes is lowest than the control mix. The results also illustrated that the density of controlled specimen is higher than density of asphaltic concrete containing 10, 20, 30, 40% coconut shell, respectively. For instance, the maximum density of AC-CS0 was 4.1% higher than the maximum density of AC-CS10. The higher density mixes is probably due to the higher specific gravity of natural aggregate compared to coconut shell.

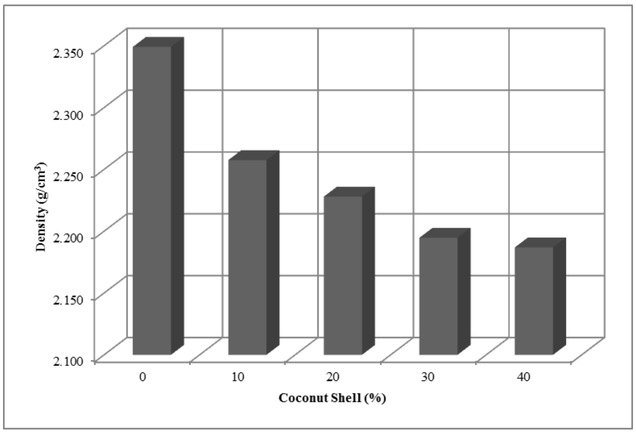


**Figure-2.** Density of asphaltic concrete at different coconut shell replacement.

### Voids in total mix

VTM is the total volume of small pockets of air between the coated aggregate particles throughout a compacted paving mixture. The effects of asphaltic concrete containing coconut shell are summarized in Figure-3. Generally, voids in total mix increase gradually with the increasing of coconut shell. The results clearly show that AC-CS40 exhibit higher VTM than AC-CS30, AC-CS20, AC-CS10, and AC-CS0, correspondingly. For instance, at 0% CS, the VTM is 3.6% while at 10, 20, 30, and 40% CS, the corresponding VTM are 5.4, 6, 6.6, and 6.8%, respectively. Hence, a 10% increase in CS content can cause an increase of VTM by 1.8%. At all VTM investigated, the 0% CS content mixes record the lowest voids in total mix.

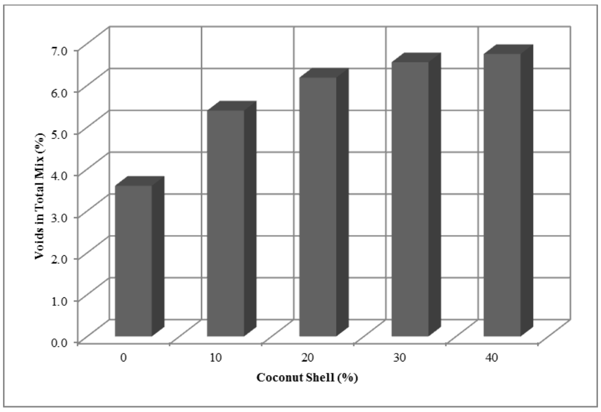


**Figure-3.** VTM of asphaltic concrete at different coconut shell replacement.

### Voids filled with bitumen

Voids filled with bitumen are the percentage of the volume of the VMA that is filled with bitumen. From the results of the investigation shown in Figure-4, the VFB decrease as increasing the percentage of coconut shell. Conventional asphaltic concrete has the highest value of VFB. This phenomenon due to the optimum bitumen content used in mixes is constant for all the percentage of coconut shell. From Figure-4, at 0% CS content, the VFB of asphaltic concrete mix approximately 76%. Therefore,

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additions of 10% CS decrease the VFB by 67.5%. According to JKR specification (JKR, 1988), the VFB should range from 75% to 85%. However, these specifications do not specify limiting values for waste materials.

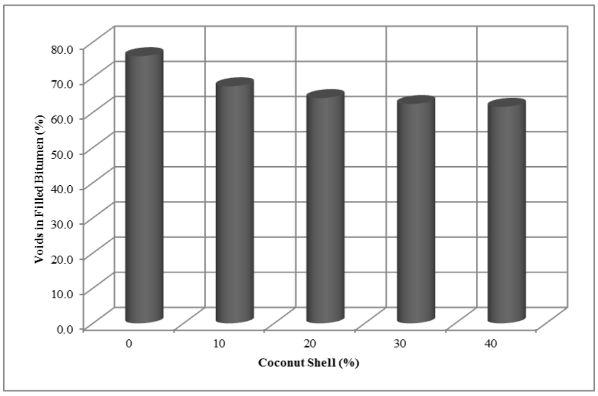


**Figure-4.** VFB of asphaltic concrete at different coconut shell replacement.

**Stability and flow**

The effect of coconut shell on stability and flow is shown in Figure-5. Generally, the stability decreases as increasing the percentage of coconut shell. Conventional specimen recorded that the higher stability was 24kN while the lowest stability is 14.78kN at 40% CS. Stability for AC-CS10 was decrease about 20% when compared to AC-CS0. Stability determines the performance of asphaltic concrete under loads. According to [18] the stability of the mixture depends on the cohesion of bitumen where bonding ability increase with increasing bitumen content. It can be seen that AC-CS40 are very easy to crack, brittle and cannot stand high load or in other word, AC-CS40 has low strength. On the other hand, the results also show that flow for the corresponding percentage of coconut shell is increase proportionally. Higher percentage of coconut shell replacement was increase the flow. AC-CS40 shows the higher flow while AC-CS0 gave the lowest flow value. This is due to more voids presenting in the specimen and make it easy to crack under loading.

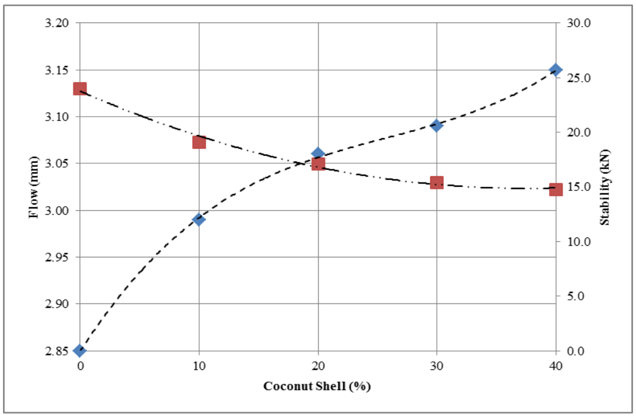


**Figure-5.** Stability and flow of asphaltic concrete vs. coconut shell.

**Indirect tensile strength**

The indirect tensile strength test results of asphaltic concrete incorporating coconut shell are graphically presented in Figure-6. Based on the figure, AC-CS10 has the highest tensile strength which is 1413 kPa and 29% higher than conventional AC-CS0. On the other hand, AC-CS40 shows the lowest tensile strength which is less than 1000 kPa. However, tensile strength for 20% of coconut shell is higher than controlled specimen was about 7%. It is shows that AC-CS10 and AC-CS20 have more quality bituminous mixture and less potential for cracking than controlled specimen.

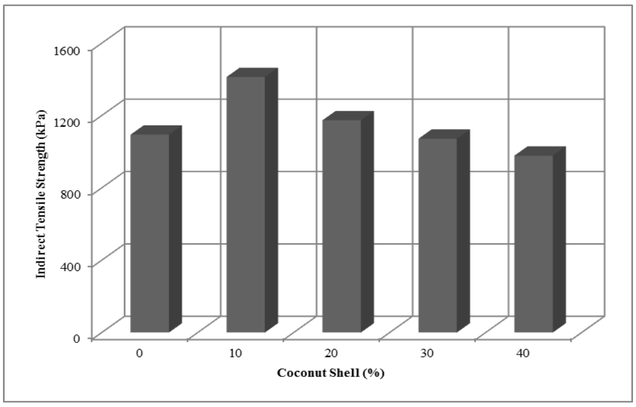


**Figure-6.** Indirect-tensile-strength vs. coconut shell.

**Resilient modulus**

The results of the resilient modulus test for mixes prepared at varying coconut shell content and temperature are presented in Figure-7. Both temperatures show similar trend when their respective resilient modulus is related to the percentage of coconut shell replacement as fine aggregate. A comparison between graphs shown in Figure-7 indicates that in general, addition of coconut shell causes an increase in the resilient modulus. The highest resilient modulus for 25 °C is 5302 MPa while for 40 °C is 785 MPa. The results also show that increasing the temperature, the resilient modulus of asphaltic concrete was decreases. The resilient modulus of asphaltic concrete reduces by approximately 75% to 85% when the test temperature increases from 25 °C to 40 °C. This result shows that asphaltic concrete are sensitive towards temperature change in term of resilient modulus. [19] found that resilient modulus has strong correlation with thermal changes. Resilient modulus is defined as the applied stress over recoverable strain. Therefore, higher resilient modulus indicates less flexibility under loading [20].

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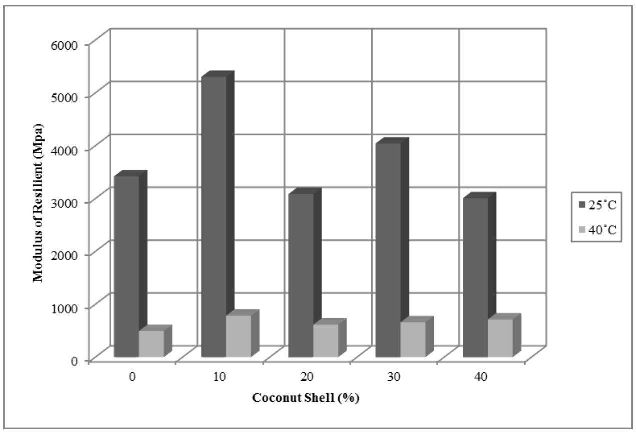


**Figure-7.** Resilient modulus vs. coconut shell at 25 °C and 40 °C.

**Dynamic creep**

Dynamic creep test is repeated load application to the asphaltic concrete and cause the development of rutting. The comparison between creep modulus of asphaltic concrete containing coconut shell is presented in Figure-8. AC-CS10 shows the highest creep modulus which is 40.72 MPa and almost double from conventional specimen. In general, the dynamic creep of specimen increase with increasing the percentage of coconut shells replacement. For instance, the maximum value of creep stiffness is 26 MPa at 0% coconut shell. However, the dynamic creep was increased about 41 MPa when coconuts shell replacement increase to 10%. It can be concluded that the incorporating of coconut shell as fine aggregate may increase the ability of asphalt mixes to reduce rutting and permanent deformation potential.

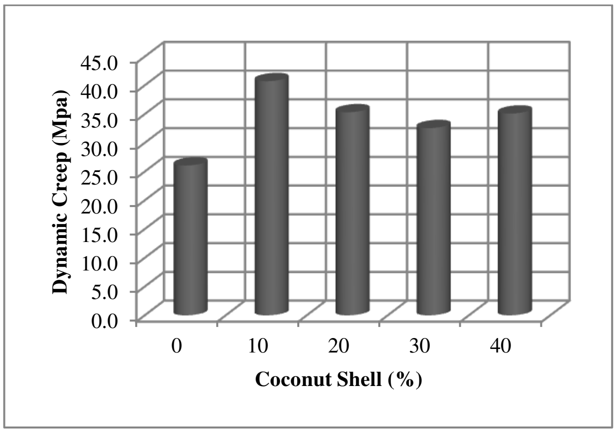


**Figure-8.** Dynamic creep vs. coconut shell at 40 °C.

**CONCLUSIONS**

From the result obtained, this study can conclude that:

a) Conventional asphaltic concrete (AC-CS0) give better volumetric properties than AC-CS. This happen due to the high void contain in coconut shell.
b) For mechanical properties, replacement 10% of coconut shell as fine aggregate (AC-CS10) shows better result than controlled specimen.
c) Hence, the optimum percentage of coconut shell replacement is 10%.

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