

# THE EFFECT OF COCONUT SHELL ON ENGINEERING PROPERTIES OF POROUS ASPHALT MIXTURE

Norhafizah M<sup>a</sup>, Ramadhansyah P. J<sup>b\*</sup>, Siti Nur Amiera J<sup>b</sup>, Nurfatin Aqeela M<sup>b</sup>, Norhidayah A. H<sup>b</sup>, Mohd Rosli Hainin<sup>b</sup>, Che Norazman C. W<sup>c</sup>

<sup>a</sup>Department of Civil Engineering, Politeknik Merlimau, KB 1031, Pejabat Pos Merlimau, 77300 Merlimau, Melaka, Malaysia

<sup>b</sup>Faculty of Civil Engineering, Department of Geotechnics and Transportation, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia

<sup>c</sup>Department of Civil Engineering, Politeknik Ungku Omar, 31400 Ipoh, Malaysia

## Article history

Received

2 December 2015

Received in revised form

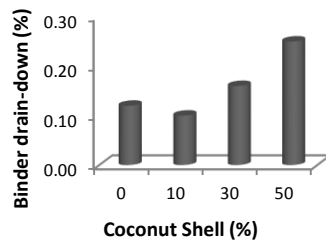
13 March 2016

Accepted

31 March 2016

\*Corresponding author  
ramadhansyah@utm.my

## Graphical abstract



## Abstract

This paper presents the results of an investigation carried out on the properties of porous asphalt mixture that are prepared by using granite aggregate and coconut shell. Four coconut shells (CS) as substitutes for conventional coarse aggregate were considered in the study: 0%, 10%, 30%, and 50% by weight of volume. The porous asphalt properties are characterized by voids in total mix, voids in filled bitumen, stability, abrasion loss, binder drainage, and permeability. In addition, the noise reductions of porous asphalt mixture were identified through impedance tube test. The results of the tests showed that coconut shell cannot be satisfactorily used as an aggregate replacement material in order to increase the properties of porous asphalt. However, in comparison between coconut shell replacement levels, 10% CS showed excellent performance. On the other hand, the incorporation of coconut shell in porous asphalt mixture has significantly reduces the traffic noise coefficient.

Keywords: Coconut shells, porous asphalt, stability, permeability, sound absorption

© 2016 Penerbit UTM Press. All rights reserved

## 1.0 INTRODUCTION

In the modern civil engineering construction, the use of alternative materials that is used to substitute natural aggregate is being actively pursued. Different alternative of materials such as coal bottom ash, blast furnace slag, fibre glass, waste plastics and others has been investigated [1-4]. In general, waste material can be classified in a two type. First, waste material can be produce from an industrial by-product such as coal ash, various slags from metal industries, industrial sludge, waste from industries like pulp and paper mills, mine tailings, food and agriculture, and leather. Secondly, includes different plastic and rubber wastes [5]. Other than industrial by-products, the agricultural

by-product can be used as an aggregate replacement. Coconut shell (CS) is one of the waste materials that can be beneficial for industry and engineering purposes. The studied of CS are varies including the use of CS as substitute to coarse aggregate in concrete [6], as a composites [7], as a seal for aerospace and automotive purpose [8] and as a heavy metal absorption for polluted water [9]. A few studies had been conducted to find the effects of CS as aggregate in concrete. For instance, Kukarni and Gaikwad [10] found that coconut shell exhibit more resistivity against impact, crushing and abrasion compared to crushed granite aggregate. However, there is no study available in determining the effect of this agricultural product as aggregate in porous

asphalt mixture. Thus, the aim of this study is to investigate the effect of coconut shell on engineering properties of porous asphalt and could be an alternative replacement of the aggregate in road industry with the indirect benefit to environmental and society.

According to the Malaysian Public Works Department specification (JKR/SPJ/2008-S4) [11], porous asphalt is a special-purpose wearing course. It is produced using open-graded aggregate mixed with polymer modified binder and contains a relatively high air voids after compaction. Porous asphalt is well-known in managing storm water and improves skid resistance, especially during wet weather. It is designed to have 18 – 25% of air voids content to ensure the drain-ability of the pavement [12]. Because of its' drain-ability properties, porous asphalt can reduce hydroplaning as well as splash and spray effect. Other than that, it is also can reduce head light reflection on wet pavement surface as well as pass-by noise.

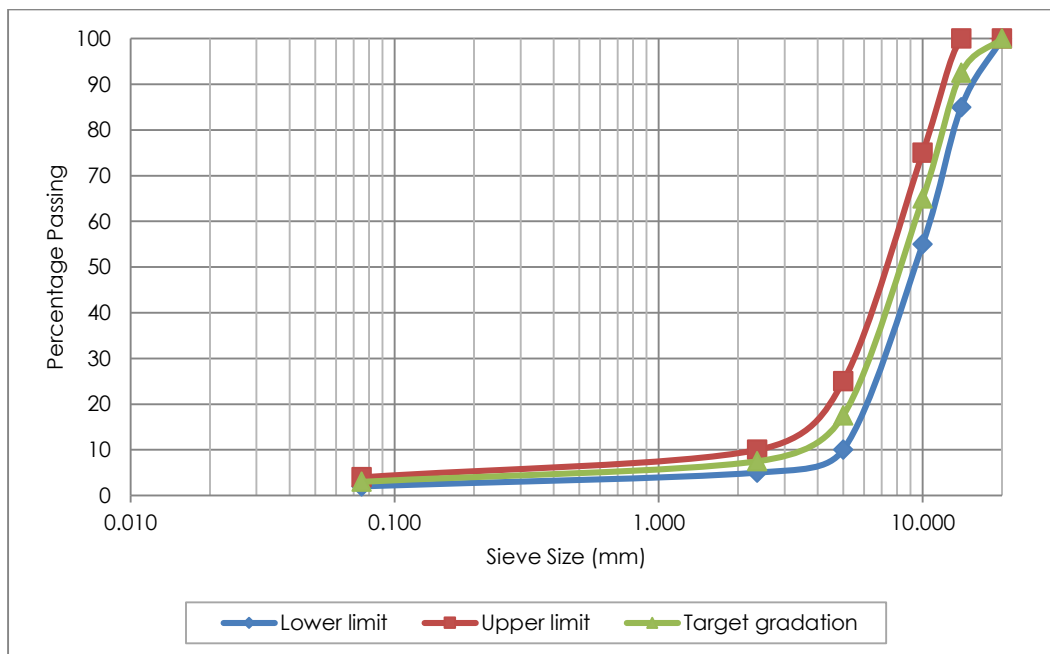
## 2.0 MATERIALS AND METHODS

### 2.1 Binder, Aggregate and Gradation

Throughout this investigation, polymer modified bitumen with performance grade of 76 were used. According to Nashruddin *et al.* [13], the specific gravity of PG-76 is 1.03 while the penetration and softening point were 43.5d-mm and 62.5°C, respectively. The granite aggregates used in this investigation is ensured massive, hard and tough [14]. The aggregate properties test results are summarized in Table 1. The gradation test was done to isolate aggregates from the stockpile to the designated sizes that would be used in mix design. In this study, the gradation shown in Figure 1 was used. The gradation test was conducted following the procedure outlined in BS EN 933-1:2012 [15] and JKR/SPJ/2008-S4 [11].

**Table 1** Aggregate properties used in this study

AIV (%)	WA (%)	Apparent SG	Bulk SG
28.5	0.50	2.635	2.600



**Figure 1** Particle Size Distribution of Porous Asphalt Mix [11]

### 2.2 Coconut Shell as Coarse Aggregate

The freshly discarded shells were collected from the local oil mills and they were first cleaned and sun dried for one week before being crushed and sieved. The particle sizes of the coconut shell used as the coarse aggregate is ranged from 5 to 20 mm. The specific gravity and water absorption values of coconut shell used in this research are determined

using ASTM C127 [16] and ASTM C128 specification [17]. The results are tabulated in Table 2. The findings indicate that the specific gravity of the CS does not fall into the category of common rock groups which is in the range of 2.62 to 3.0 [18]. While the water absorption of CS exhibit higher than acceptable value which is more than 2%. Higher water absorption and low specific gravity is expected indicate low material strength. However, in contrary, the CS shows

less percentage of impact value than the conventional aggregate. It can be said that coconut shell has a higher resistance to a sudden shock or impacts. The shape and the arrangement of coconut shell particles which are plate and overlapping each other is accounted for this situation.

**Table 2** Physical Properties of Coconut Shell

AIV (%)	WA (%)	Apparent SG	Bulk SG
5.70	24.0	1.440	1.070

### 2.3 Mix Preparation and Test

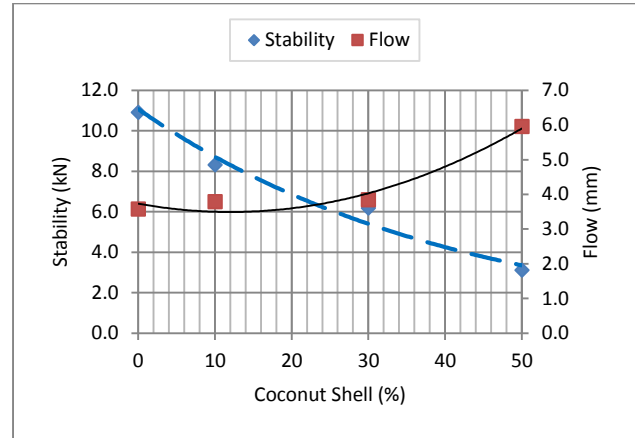
Two types of aggregates, CS and granite were used in preparing the porous mixes. Four proportions CS that are used as aggregate replacement in the study that are 0%, 10%, 30%, and 50%. The proportions of CS are calculated by weight of volume. For this study, coarse aggregates (size between 5 to 20 mm) are used as a replacement. Porous asphalt mixtures that consist of aggregate, binder and CS are mixed at  $190 \pm 0.5^\circ\text{C}$  and compacted at  $180 \pm 0.5^\circ\text{C}$ . The mixes were compacted with 50 blows on each side with the standard Marshall hammer to avoid disintegration of materials. After compaction, the specimens are removed from the moulds and allowed to cool down. The performance of porous asphalt mix incorporating coconut shell are evaluated through volumetric properties, stability [19], permeability, binder drainage [20], and abrasion loss [21]. In addition, sound absorption of specimens is identified through impedance tube test [22].

## 3.0 RESULT AND DISCUSSION

### 3.1 Stability and Flow

The effect of porous asphalt mixture containing coconut shell on stability and flow are shown in Figure 2. It could be seen that the stability sensitive towards variant of CS content. Higher CS percentages have the net effect of decreasing mix stability. This is due to higher water absorption and low specific gravity consequently caused a lower strength. The average stability of conventional porous mix is 10.9kN. The stability drop from 8.3 to 3.1kN as the coconut shell replacement increases from 10 to 50%. In general, when compared between coconut shell replacement, 10% CS porous asphalt mix exhibited the highest stability than 30% CS and 50% CS. Thus, 10% replacement of CS with aggregate is considered as the optimal limit. Furthermore, the differential movement between initial and maximum loading is recorded as the flow. Based on Figure 2, the results show that flow for the corresponding coconut shell content increases proportionally. The

maximum flow for conventional mix is 3.6 mm. Porous asphalt specimen incorporating coconut shell on the other hand exhibit a maximum flow of 5.9 mm at 50% CS content. Rafi *et al.* [23] and Pourtahmasb and Karim [24] reported that a maximum flow of 16 mm is often specified for mix design and construction control.



**Figure 2** Relationship between stability and flow at different percentage coconut shell

### 3.2 VFB and VTM

Voids Filled Bitumen (VFB) is the percentage of the volume of the VMA that is filled with bitumen. The VFB is inversely related to the air voids. As the percentage of air voids approaches zero, the VFB approaches 100 [25]. The general effect of porous asphalt mix containing coconut shell on VFB is presented in Figure 3. It can be seen that the VFB decreases as the coconut shell quantity increases. The VFB reduces from 62.1% to 45.2% as the coconut shell content increases from 0% to 50%. According to JKR specification [11], the VFB should range from 75% to 85%. However, the specification does not specify limitation values for porous asphalt, especially for incorporated with waste agriculture materials. In addition, Voids in Total Mix (VTM) also has been investigated in this study and the results are illustrated in Figure 3. Clearly, the trend is quite inconsistent for majority of mixes. The control sample or 0% CS mix exhibits the highest VTM followed by CS-10 and CS-30, correspondingly. However, at 50% CS mixes in increasing VTM value. Yi [14] and Wan *et al.* [26] reported that lower air void contents minimize the aging of the asphalt cement films within the aggregate mass and also minimize the possibility of moisture penetrating the thin asphalt cement film and strip the asphalt cement off aggregates. In this investigation, the lowest VTM value of porous asphalt containing coconut shell mix was recorded at 10% and 30%, respectively.

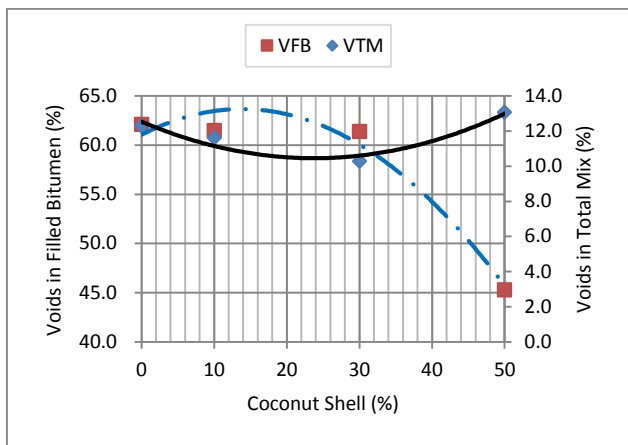


Figure 3 Relationship between VFB and VTM at different percentage coconut shell

### 3.3 Loss of Abrasion

The resistance of compacted porous mixes coconut shell to abrasion loss is analyzed by means of the Cantabrian test. The abrasion loss is expressed in terms of the percentage mass loss compared to the original mass. Figure 4 shows the relationship between abrasion loss and coconut shell at different percentage replacement. The amount of abrasion loss indicates the inter-aggregate particle cohesion loss in the porous mixes tested. Clearly, porous asphalt mixes containing coconut shell generally exhibits lower resistance to abrasion than mixes containing 0% CS. For instance, at 0% CS, the abrasion loss of mix is 7.6% while the equivalent value for 10% CS mix was 13.1%. It can be concluded that addition of CS in higher quantities does not increase resistance to abrasion and the subsequent mix durability. However, when compared between CS replacement, 10% CS mix is the most resistant to abrasion followed by 30 and 50% CS. It can said that the lower the abrasion loss, the less prone the mixtures to disintegration [26].

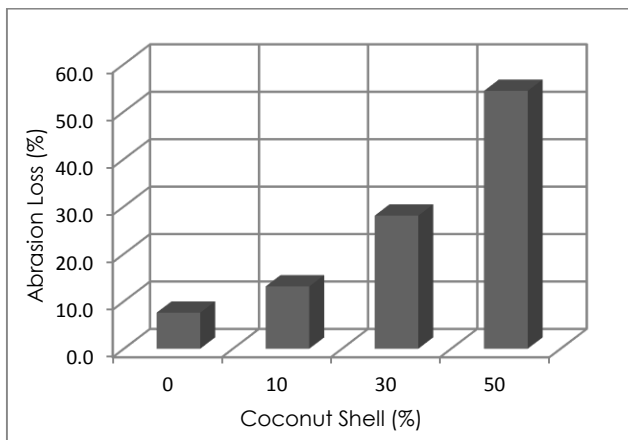


Figure 4 Loss of abrasion porous asphalt mixture incorporating coconut shell

### 3.4 Binder Drainage

Figure 5 illustrates the increment in binder drain-down as the coconut shell content increases. The results clearly show that binder drain-down for 10% CS drop by 0.02 compare than conventional porous asphalt which is from 0.12 to 0.1 and subsequently increasing from 0.15% to 0.25% for 30% CS and 50% CS, respectively. Hence the use of 10% CS is an optimal limit of incorporating mixture that can help to mitigate the problem of binder drainage compared to conventional mix.

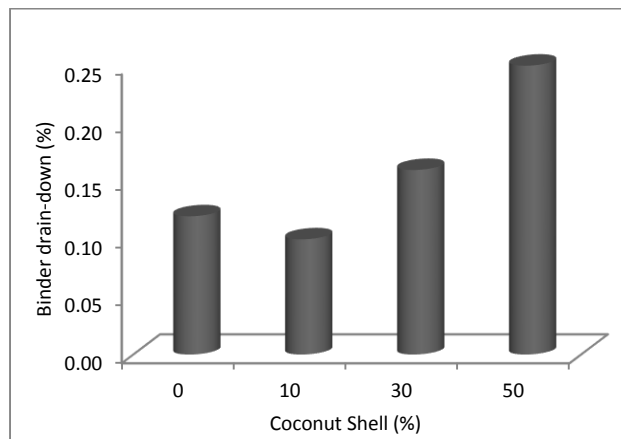


Figure 5 Binder drain-down of porous asphalt mixture incorporating coconut shell

### 3.5 Sound Absorption Coefficient

The impedance tube method was used in this study to evaluate the normal incidence sound absorption coefficient in porous asphalt mixtures incorporating coconut shell. In the laboratory, the acoustic spectra were measured 2-3 times for each specimen whereby the porous asphalt was set in and taken off from the sample holder repeatedly. The measurements were carried out without changing the direction of specimens to sound source. Figure 6 illustrates the significant role played by the coconut shell as coarse aggregate in porous asphalt. For all mixes, conventional and modified specimen exhibits similar pattern. The peak frequencies for all porous asphalt mix show small variation within  $\pm 100$  Hz. The sensitivity of the peak frequency and the maximum acoustic absorption coefficient which are ranged within  $\pm 100$  Hz and  $\pm 0.1$ , respectively, are not critical problems [27]. The porous asphalt in this study was normally applied as pavement used for reducing the reflected traffic noise and tyre-road interaction noise range from 0 Hz to 1600 Hz. From Figure 6, the curve of the specimen generally showed three frequencies peak. The first frequencies peak, detected between 100 to 700 Hz, with the sound absorption coefficient ( $\alpha$ ) was 0.05 to 0.06. The second frequencies peak located between 700 and 1000 Hz, with a maximum peak at 850 Hz and a 0.89 absorption coefficient. Lastly, the third frequencies peak observed between

1000 and 1600, with a coefficient absorption in range of 0.62 to 0.18. Based on figures, it is found that noise reduction due to an increase in air void content (Figure 7) is likely to be significant in the frequency ranges of 700 and 1000 Hz. As expected, an increase in the air voids percentage, leads to a greater absorption. Finally, it can be concluded that the average percentage coconut shell addition, of 30 %, led to a greater absorption coefficient. Porous surfaces are very popular for traffic noise reduction due to their aptitude to absorb noise. A survey indicated they can reduce the pass-by noise by 1 to 9 dB (A) as opposed to a conventional layer [28].

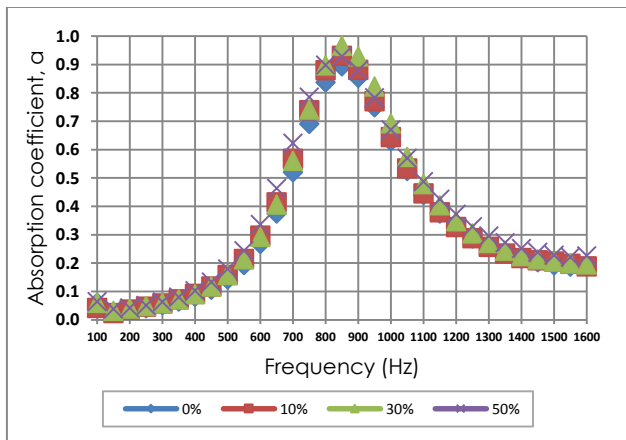


Figure 6 Sound absorption coefficients at varying coconut shell replacement

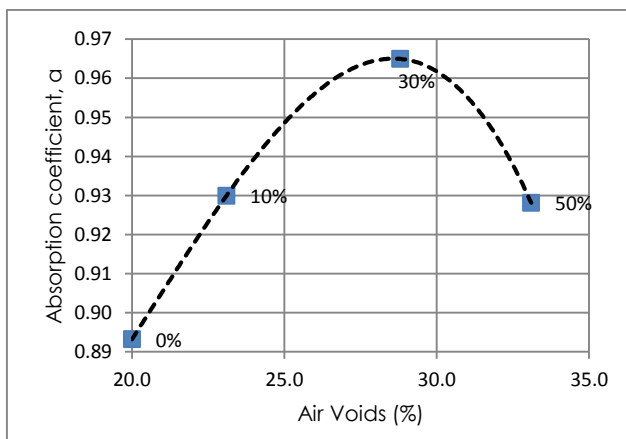


Figure 7 Correlation between sound absorption vs. air voids

3.6 Permeability, Porosity and Coconut Shell

Figure 8 shows a typical relationship between permeability and porosity of porous asphalt mix prepared at varying coconut shell replacement. The two Y-axis represent porosity and permeability whereas the X-axis represents the percentage of coconut shell. Each plotted point is an average of two readings. The figure also shows that an increase in coconut shell content causes a corresponding

increase in porosity and permeability. Specimens with 0% CS replacement had lower coefficient permeability (k) where 50% CS content had higher permeability coefficient (k) and followed by 30 CS and 10% CS respectively. Generally, porous asphalt mixes are more permeable and porous than other types of mix. The permeability coefficient of coconut shell mixes increases from 0.24 cm/s to 0.83 cm/s as the coconut shell content increases from 0% to 50%. The porosity results also register the same trend with the replacement of coconut shell. This means that the replacement of coconut shell to porous mixes can increase the porosity and permeability. However, the increase in permeability coefficient is cannot be attributed to the progressive clogging of the pores by the replacement coconut shell.

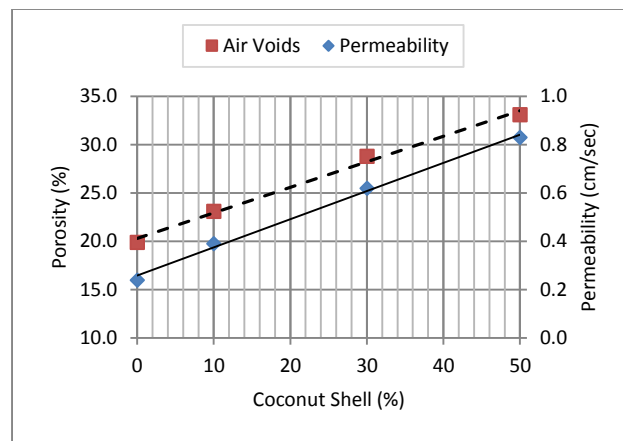


Figure 8 Correlation between porosity and permeability at different level coconut shell

4.0 CONCLUSION

The effects of coconut shell on the porous asphalt mixture properties were investigated. It was found that the addition of coconut shell as aggregate replacement materials cannot improve the engineering properties of porous asphalt mixture. However, when compared among substitutes level, the use of 10% CS resulted in good performance of mixtures. Furthermore, coconut shell has the advantages and effective in reducing sound absorption coefficient at 30% replacement.

Acknowledgment

The support provided by Malaysian Ministry of Higher Education and Universiti Teknologi Malaysia in the form of a research grant (Vote No. Q.J130000.2522.06H53) for this study is very much appreciated.

## References

- [1] L. B. Andrade, J. C. Rocha, M. Cheriaf. 2009. Influence Of Coal Bottom Ash As Fine Aggregate On Fresh Properties Of Concrete. *Construction and Building Materials*. 23(2): 609-614.
- [2] M. Valcuende, F. Benito, C. Parra, I. Miñano. 2015. Shrinkage Of Self-Compacting Concrete Made With Blast Furnace Slag As Fine Aggregate. *Construction and Building Materials*. 76:1-9.
- [3] S. T. Tassew and A. S. Lubell. 2014. Mechanical Properties Of Glass Fiber Reinforced Ceramic Concrete. *Construction and Building Materials*. 51: 215-224.
- [4] J. R. Correia, J. S. Lima, J. de Brito. 2014. Post-Fire Mechanical Performance Of Concrete Made with Selected Plastic Waste Aggregates. *Cement and Concrete Composites*. 53: 187-199.
- [5] K. McNeil, Thomas H. K. Kang. 2013. Recycled Concrete Aggregates: A Review. *International Journal of Concrete Structures and Materials*. 7(1): 61-69.
- [6] Yerramala A. and Ramachandrudu C. 2012. Properties of Concrete with Coconut Shells as Aggregate Replacement. *International Journal of Engineering Inventions*. 1(6): 21-31.
- [7] Sapuan S.M., Harimi M. and Maleque M. A. 2003. Mechanical Properties of Epoxy/Coconut Shell Filler Particle Composites. *The Arabian Journal for Science and Engineering*. 28(2B).
- [8] Latif, M. S. 2005. *Alloy Material with Carbon Contain from Coconut Shell Material for Seal*. Melaka: Kolej Universiti Teknikal Kebangsaan Malaysia.
- [9] Okafor P. C., Okon P. U., Daniel E. F. and Ebenso E. E.. 2012. Adsorption Capacity of Coconut (Cocos nucifera L.) Shell for Lead, Copper, Cadmium and Arsenic from Aqueous Solutions. *International Journal of Electrochemical Science*. 7: 12354-12369.
- [10] Kukarni V. P & Gaikwad S. K. B. 2013. Comparative Study on Coconut Shell Aggregate with Conventional Concrete. *International Journal of Engineering and Innovative Technology (IJEIT)*. 2(12).
- [11] Nashruddin T.F., Ramadhansyah P.J., Norhidayah A.H., Hasanani Md. N., Md. Maniruzzaman A. A., Che Norazman C.W. 2014. Evaluation of Binder Absorption in Asphalt Mixture with Various Aging Conditions Using Rice Method. *Jurnal Teknologi (Sciences & Engineering)*. 71(3): 53-56.
- [12] T. C. Yi. 2008. *Performance Evaluation of Steel Slag as Natural Aggregates Replacement in Asphaltic Concrete*. MSc. Thesis, Universiti Sains Malaysia.
- [13] BS EN 933-1. 2012. *Tests for Geometrical Properties Of Aggregates. Determination Of Particle Size Distribution*. Sieving method. British European Standard, UK.
- [14] ASTM C127. 2012. *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate*. Annual Book of ASTM Standards, West Conshohocken, Philadelphia, U.S.A.
- [15] ASTM C128. 2012. *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate*. Annual Book of ASTM Standards, West Conshohocken, Philadelphia, U.S.A.
- [16] Neville, A. M. 2012. *Properties of Concrete*. 5<sup>th</sup> Edition. Edinburgh Gate, Scotland: Pearson Education, Asia Pte. Ltd.
- [17] ASTM D6927. 2006. *Standard Test Method for Marshall Stability and Flow of Bituminous Mixtures*. Annual Book of ASTM Standards, West Conshohocken, Philadelphia, U.S.A.
- [18] BS EN 12697-18. 2004. *Bituminous Mixtures. Test Methods For Hot Mix Asphalt. Binder Drainage*. British European Standard, UK.
- [19] ASTM C131. 2014. *Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*. Annual Book of ASTM Standards, West Conshohocken, Philadelphia, U.S.A.
- [20] ASTM E1050. 2012. *Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones and a Digital Frequency Analysis System*. Annual Book of ASTM Standards, West Conshohocken, Philadelphia, U.S.A.
- [21] Rafi MM, Qadir A, Siddiqui SH. 2011. Experimental Testing Of Hot Mix Asphalt Mixture Made Of Recycled Aggregates. *Waste Management & Research*. 29(12): 1316-26.
- [22] M. S. Pourtahmasb and M. R. Karim. 2014. Utilization of Recycled Concrete Aggregates in Stone Mastic Asphalt Mixtures. *Advances in Materials Science and Engineering*. 2014: 1-9.
- [23] M. M. Samat. 2006. *The Effects of Drain Asphalt Modified Additive (DAMA) on the Engineering Properties and Performance of Porous Asphalt*. MSc. Thesis, Universiti Sains Malaysia, Malaysia.
- [24] Wan, C. N. C., Jaya, R. P., Hamzah, M. O. 2012. Properties Of Porous Asphalt Mixture Made with Styrene Butadiene Styrene Under Long Term Oven Ageing. *Advanced Materials Research*. 486: 378-383.
- [25] H. K. Kim and H. K. Lee. 2010. Influence Of Cement Flow And Aggregate Type on the Mechanical And Acoustic Characteristics Of Porous Concrete. *Applied Acoustics*. 71(7): 607-615.
- [26] Ahammed M. A. and Tighe S. L. 2011. Acoustics Absorption of Conventional Pavements. *International Journal of Pavement Research and Technology*. 4(1): 41-47.
- [27] Tarmuzi, N. A., Jaya, R. P., Yaacob, H., Hassan, N. A., Aziz, M. M. A. 2015. Aggregate Angularity Effect On Porous Asphalt Engineering Properties And Performance. *Jurnal Teknologi*. 73(4): 99-104.
- [28] Lay Ting, T., Putra Jaya, R., Abdul Hassan, N., Yaacob, H., Sri Jayanti, D. 2015. A Review Of Utilization Of Coconut Shell And Coconut Fiber In Road Construction. *Jurnal Teknologi*. 76(14): 121-125.