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# Evaluating properties of wood ash modified asphalt mixtures

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**Abstract.** Nowadays, sustainable development has gained more attention because humanity will face the problem of energy shortage in the near future. Biomass' consumption has increased year by year as it is a renewable material. However, there will be a lot of ash residue after combustion biomass, which can cause pollution problems. This research investigates the potential use of wood ash as filler replacement in the asphalt mixture because wood ash has similar physical and chemical properties to traditional fillers. Wood ash used in this study consisted of 100% passing the 0.075 mm sieve and 25%, 50%, 75% and 100% conventional filler (by weight) were replaced by the wood ash. Marshall Stability & Flow, Resilient Modulus, Rutting performance and Fatigue performance tests were employed to determine the influence of wood ash as filler to the hot mix asphalt (HMA) mixture. The results showed that present wood ash in the asphalt mixture could improve fatigue performance, reduce permanent deformation, and increase the resilient modulus of the asphalt mixture. Therefore, wood ash can be used as the filler substitute material for asphalt mixture.

## 1. Introduction

With the development of the economy and the improvement of people's living standards, passenger car has become popular choice of transportation among ordinary families. According to the Statistics portal [1], the number of passenger cars increased from 679 million in 2005 to 947 million in 2015. In addition, with the rapid development of the logistics industry, more and more large trucks are designed to carry goods to meet people's demand for various materials. Some countries have even raised legal axle loads such as South Africa, Egypt and India. It is a fact that both increase of the number of vehicles and increase of the axle load will increase pavement distress and thus reduce the pavement life. Heavier axle load truck will cause more damage to the pavement as compared to the larger number of passenger cars since the damage to the pavement is not linear with axle load increased but exponential.

In general, there are two ways to improve the performance of the pavement. First is to find a suitable mix design, and the second way is to utilize the proper material. There are three materials in asphalt mixtures namely aggregate, bitumen and filler. The choice of aggregate is largely limited by location. Modified bitumen has been populated nowadays. Filler as one of the materials also played a major role in the asphalt mixture [2]. There are two mechanisms to describe the role of filler in asphalt mixes. Firstly, fillers provide additional contact points between larger aggregates. Secondly, fillers increase the stability of the mix by increasing the viscosity of asphalt binders [3]. During the mixing, filler will blend with bitumen to form asphalt mastic, which plays a major role in controlling the mechanical properties of their mixtures [4]. The type of filler affects the performance of asphalt



mixture. Mistry and Roy [5] carried out research on the effect of fly ash as filler in the hot asphalt mix, and the results shown that fly ash as the filler replacement in hot mix asphalt (HMA) can give lesser deformation and better strength compared with hydrated lime. Modarres and Rahmzadeh [6] examined the effect of coal waste power as filler in hot mix asphalt (HMA), and the obtained results showing that the indirect tensile strength, Marshall Stability, and resilient modulus of hot mix asphalt (HMA) mixes were increased by using coal waste power as filler compare with limestone powder.

As a renewable resource, biomass is now being paid more attention by human beings. In 2017, about 5% of the total primary energy was provided by biomass fuels in the United States [7]. Because coal resources will be fully used in the near future, biomass is being used by more and more power plants as substitutes for coal. However, combustion biomass fuels will produce large amounts of ash residues. These ashes are usually in the forms of fine particles that can be easily blown away by the wind, thus cause air pollution and human health problems. Usually, these ash will be landfilled but it will wasted land and cause groundwater pollution because the ash contains some heavy metals that will enter the groundwater system with rainfall. Some researchers have attempted to use these biomass ashes as fillers in the asphalt mixture. Sargin at al. [8] investigated the effect rice husk ash as filler in hot mix asphalt (HMA) concrete. It found that the best Marshall Stability results were obtained when the filler was composed of 50% limestone and 50% rice husk ash. Al-Hdabi [9] researched on the properties of asphalt concrete mixture with rice husk ash as filler by conducting an Indirect Tensile Strength, Index of Retained Strength and Marshall Stability tests. It concluded that by replacing conventional mineral fillers with rice husk ash, the Marshall stability of hot asphalt mixtures is significantly improved. Tahami et al. [10] investigated the potential of using date seed ash and rice husk ash as filler in hot mix asphalt (HMA). The results shown that the asphalt mixtures with date seed ash and rice husk ash fillers have significantly improved stability and stiffness modulus compared to the control mixtures. However, for wood ash as the major components of biomass ash, only a few researchers tried to study the possibility of it as a partial replacement for pavement material, especially in Malaysia. This study was designed to evaluate the potential of wood ash as filler substitute material for the production of asphalt mixtures. Ranges of percentages of 25%, 50%, 75% and 100% of conventional filler were replaced by the wood ash to produce asphalt mixture. Then, those specimens were subjected Marshall Stability & Flow test, asphalt permanent deformation test, Indirect Tensile Fatigue test and Resilient Modulus test and the results were compared to control samples.

## 2. Materials and experiment design

### 2.1. Aggregates

The aggregate used in this study is sharp-edged and crushed granite aggregates which are obtained from quarry in Kajang, Malaysia. The grading of aggregate is following the JKR/SPJ/2008-S4 requirement of AC 10 [11] as shown in table 1. The average specific gravity of aggregate is 2.57.

**Table 1.** Gradation of Aggregate

Sieve Size (mm)	Specification		Passing (%)
	Upper Limit	Lower Limit	
14	100	100	100
10	100	90	95
5	72	58	65
3.35	64	48	56
1.18	40	22	31
0.425	26	12	14
0.15	14	6	10
0.075	8	4	6
Pan	0	0	0

### 2.2. Asphalt binder

The asphalt used for this study is a penetration grade of binder 60/70 (PEN 60/70) obtained from the same quarry in Kajang. The specific gravity of asphalt is 1.03.

### 2.3. Wood ash

The wood ash obtained from a pottery company located in Kuala Selangor. The wood ash was dried in an oven at a temperature of 110°C before use. It was then sieved through a 425µm sieve in order to remove the debris and extraneous materials. The retained wood ash then milled and sieve through a 75µm sieve. The properties of the wood ash as shown in Table 2.

**Table 2.** Properties of Wood Ash

Chemical Composition%	
CaO	29.53
K <sub>2</sub> O	9.64
SiO <sub>2</sub>	28.11
MgO	5.14
SO <sub>3</sub>	0.97
Al <sub>2</sub> O <sub>3</sub>	5.14
Fe <sub>2</sub> O <sub>3</sub>	2.91
P <sub>2</sub> O <sub>5</sub>	2.48
Na <sub>2</sub> O	0.32
Specific Gravity (g/cm <sup>3</sup> )	2.52
Median Particle Size, d <sub>50</sub> (µm)	22.486

### 2.4. Sample preparation

The Marshall Mix design method was employed to prepare asphalt mixture samples with 75 blows on each side of the cylindrical samples. The specified procedure in ASTM D6926 [12] for heating, mixing and compaction the asphalt cement-aggregate mixture was followed. The Optimum Asphalt Content (OAC) was found to be 5.7% for the control mixture and all hot mix asphalt (HMA) samples were prepared using this OAC to maintain consistency throughout the study. For each different percentage (0%, 25%, 50%, 75%, and 100%) of wood ash as filler, three asphalt mixture samples need to be prepared for each test. However, for Marshall Stability & Flow and Resilient Modulus tests, they can utilize the same sample because resilient modulus test is non-destructive test and the sample after resilient modulus test can still be used in Marshall Stability & Flow test.

## 3. Experimental procedure

### 3.1. Marshall stability & flow test

The purpose of the Marshall Stability & flow test is to determine the Marshall stability and flow values of asphalt mixture. The maximum allowable aggregate size in this experiment is 25mm and it is conducted based on ASTM D1559. Samples were immersed in a 60°C water bath for 30 minutes before testing. A load with a constant strain rate of 50.88 mm/min was applied to the sample until maximum load reached. The Marshall Stability and flow values read from the display of Marshall Apparatus. The corrected Marshall Stability values obtained by multiplying the Marshall stability with Height correlation ratio.

### 3.2. Resilient modulus test

Resilient Modulus Test is to measure of material stiffness. In pavement design, stiffness of asphalt mixture are tested by using Material Testing Apparatus (MATTA) in the resilient modulus test. And,

this test is carried out according the ASTM D4123 [13]. Samples were placed in a MATTA machine for at least 2 hours at 25°C before testing. The peak load force used in this test is 1200 N.

### 3.3. Rutting performance test

The rutting performance of asphalt mixture was determined by MATTA machine in asphalt permanent deformation test. The samples were subjected 200 kPa force for 3600 cycles at 40°C. The rest period and load repeat time was 0.1s and 0.5s, respectively.

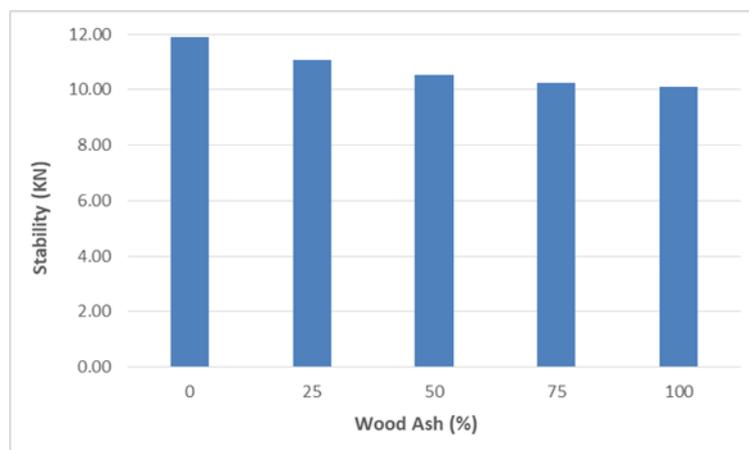
### 3.4. Fatigue performance test

In this study, Indirect Tensile Fatigue test was adopted to test the fatigue performance of asphalt mixtures. The test machine is the same as the rutting performance test. The cyclic loading force was 1000 N for 3600 loading cycle at 20°C. And, load repeat time was 500ms with 100ms rest time.

## 4. Results and discussion

### 4.1. Marshall stability & flow test results

The Marshall Stability for all of the asphalt mixture is shown in Figure 1. From the figure, the present of wood ash will reduce Marshall Stability, and by increasing the wood ash content, the stability was decreased. That's because wood ash has lower ductility compared to traditional fillers. However, all of the stability values are still significant larger than JKR/SPJ/2008-S4 requirement for AC10 which is larger than 8 KN. The mixture produced with 25% wood ash and 100% wood ash had 6.8% and 15.1% lower stability than control group.



**Figure 1.** Marshall Stability of all asphalt mixtures.

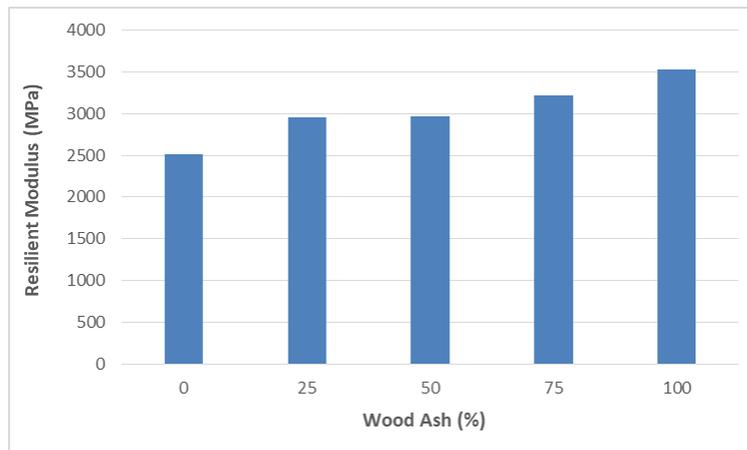
Table 3 shows results of few parameters for different wood ash content at OAC and the JKR requirement. As shown in Table 3, all of the flow values are fulfil the requirement, and flow value is decreased with the increasing of wood ash content from 25% to 100%. It means that wood ash has lower flexibility and addition wood ash in the asphalt mixture could reduce the flexibility of the mixture. Besides, the stiffness value is increased with the increasing of wood ash content from 25% to 100%. The stiffness of control and 100% wood ash mixture were found to be 3514 N/mm and 3820 N/mm. The stiffness of the asphalt mixture can predict permanent deformation and rutting. The higher the stiffness value, the stiffer the asphalt mixture and the better resistance to permanent deformation [14, 15].

**Table 3.** Results and Requirements.

Parameter	Specification (JKR 2008)	Wood Ash Content				
		0%	25%	50%	75%	100%
Stability (N)	> 8000	13670	12730	12390	12340	12300
Flow (mm)	2-4	3.89	3.99	3.97	3.25	3.22
Stiffness (N/mm)	>2000	3514	3190	3121	3797	3820

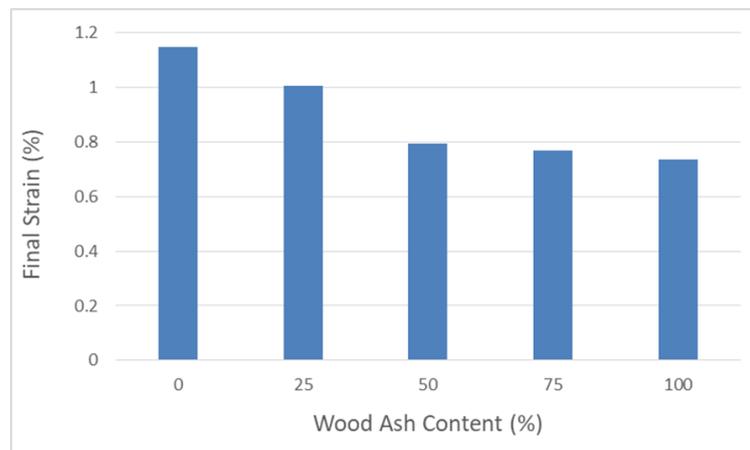
#### 4.2. Resilient modulus test results

Figure 2 shows the results of the resilient modulus of all asphalt mixtures. The figure shows that using wood ash could improve the resilient modulus of asphalt mixtures, and by increasing the wood ash content, the resilient modulus was increased. This is because wood ash has a lower specific gravity than conventional fillers and it can fill more gaps/voids in the asphalt mixture than conventional fillers. The mixture produced with 25% wood ash and 100% wood ash had 17.5% and 40% higher resilient modulus than control group. This means that the stiffness of the asphalt mixture was improved due to the presence of wood ash.

**Figure 2.** Resilient Modulus of all asphalt mixtures.

#### 4.3. Rutting performance test

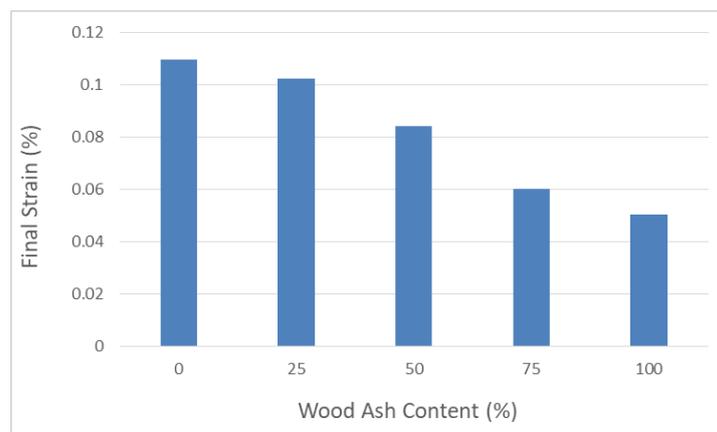
The final strain of rutting performance for all of the asphalt mixture is shown in Figure 3. It shows that control group have more permanent deformation compared to the Wood Ash modified asphalt mixtures. As the wood ash content increases, permanent deformation will decrease. The reason for this phenomenon is that the wood ash has low thermal sensitivity. The more wood ash content in the mixture, the less the effect of temperature on the asphalt mixture and the good permanent deformation resistant.



**Figure 3.** Final strain of rutting for all asphalt mixtures.

#### 4.4. Fatigue performance test

Figure 4 present the final strain of fatigue for all asphalt mixtures. The figure shows that addition wood ash in asphalt mixture could reduce the final strain of samples. This means that fatigue performance can be improved by adding wood ash to the asphalt mixture. And as the wood ash content increases, better fatigue performance will be in the end. Which is because the addition of wood ash in the asphalt mixture can reduce the gaps/voids in the asphalt mixture and improve the adhesion between the asphalt binder and the aggregates [16].



**Figure 4.** Final strain of fatigue for all asphalt mixtures.

## 5. Conclusion and recommendation

From the results, the present of wood ash can significantly improve the resilient modulus of the asphalt mixture, and by increasing the wood ash content, the resilient modulus was increased. But, the stability was decreased with increased of wood ash content. However, those stability values still fulfilled the JKR requirement. As the wood ash content increases, permanent deformation was decrease and fatigue performance was improve. Therefore, wood ash as a sustainable material and are suitable as a replacement material for conventional fillers for the production of hot mix asphalt (HMA) by using AC 10 gradation and PEN 60/70 asphalt binder. Wood ash used as a filler replacement material not only can improve properties of the asphalt mixture but also reduce environmental pollution. Further study is needed to evaluate the effect of wood ash as filler on asphalt mixture by using different gradation and binder types. In addition, wood ash may also be used as an asphalt modifier to improve the quality of the asphalt mixture.

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