The Use of Palm Oil Fuel Ash as a Filler in Asphaltic Concrete Mixtures

Goh Boon-Hoe, Abdullahi Ali Mohamed, Yeong Tuck-Wai

Abstract: The study was conducted to evaluate the application of Palm Oil Fuel Ash (POFA) as a filler material. POFA was incorporated into asphalt mixes by using dry process method. Dense-graded ACW14 was selected with 80/100 penetration grade bitumen as binder. POFA was collected from boilers at Seri Ulu Langat Palm Oil Mill. Two types of POFA varying in amount of un-burnt carbon content were examined and compared with conventional mixture. All samples were tested for Marshall Stability, Flow and Volumetric properties. Results showed that POFA modified samples showed better performance levels than conventional samples, but exhibited higher optimum bitumen contents (OBC). HMA modified with POFA containing high carbon content had the highest Marshall Stability and Stiffness values of the 3 sets, at the same time having an OBC just a little higher than the control set. However, it exhibited VFA values slightly below specifications.
Keywords: Palm Oil Fuel Ash, Hot Mix Asphalt, Marshall Test, Optimal Bitumen Content, Marshall Stability, Bulk Density.

This paper presents a study of laboratory evaluation on the performance of Stone Mastic Asphalt (SMA) using Palm Oil Fuel Ash (POFA) as filler material. POFA produced by burning palm fibre and shell which is generally used as boiler fuel to produce steam for electricity generation in the mill. POFA is one of the materials identified to have a potential of becoming an alternative filler material in SMA mixes. In this project, a small portion of POFA (passing 75Âµm) was used to modify asphalt mixtures. POFA was incorporated into asphalt mixes by using dry process method which refers to technologies that mix POFA with the aggregate prior to mixing it with asphalt binder. The aggregate gradations use in this study is gap graded (stone mastic asphalt with 14mm nominal maximum aggregate size-SMA14). The percentage of POFA added was varied from 0 to 7 % (2% hydrated lime) by weight of the total aggregate which is 0 to 100% by weight of the filler content. Samples was prepared and compacted using Marshall Method. Several performance indicators of mixes was evaluated using laboratory work were moisture induced damage/stripping resistant and Marshall volumetric properties. The performance results of modified asphalt mixes were compared to conventional asphalt mixes (unmodified samples). Based on the results, the performance of HMA mixes such as stability, flow and stiffness was significantly affected with the addition of POFA. The results suggest that 50% POFA by weight of filler content is the optimum value

1. Introduction

The use of waste material in bituminous mix has undergone considerable development in recent years. In spite of the small proportion of these materials added to the binder, the high cost incurred may cut down the use of modified bitumen in road building. Numerous studies have been carried out to incorporate waste materials into Hot Mix Asphalt (HMA). These include scrap rubber, waste glass, boiler ash, incinerator residue, coal-plant refuse (Kandhal P. S., 1992) and steel slag (Huang et al., 2007). Most of the researches have focused on utilization of waste and industrial by-products so as to reduce construction costs as well as prevent environmental degradation. POFA is one such by-product that has been suggested and researched to a certain extent. Abdullah et al. (2006) showed POFA to be a suitable partial replacement of Ordinary Portland Cement (OPC) in aerated concrete. In 2009, Tonnayopas et al's investigation showed positive influence of POFA on properties of hardened concrete. However, research of POFA as a suitable replacement for conventional stone dust filler in HMA have been few and far between. Studies have been carried out to evaluate the performance of Marshall properties of HMA with POFA as filler. Dukatz & Anderson (1970) investigated the effects of eight different filler materials on mechanical properties of HMA and concluded that different filler materials have different effects on stiffness but almost no effect on Marshall Stability or void ratio. Asi & Assa'ad (2005) found that asphalt concrete mixes prepared by replacing 10% of conventional stone dust filler with Jordanian oil shale fly ash provided the best improvement in mechanical properties of the mix. Sharma et al. (2010) concluded that bituminous mixture made using fly ash as mineral filler showed better properties than those made with stone dust filler. Other waste fillers that have been studied include marble waste dust (Karaşahin & Terzi, 2007), cement bypass dust (Ramzi Taha et al. 2002) and coal ash (Churchill & Amirkhanian, 1999). Taking cue from other countries, Malaysia has identified POFA, an abundant waste product, as possible substitute filler in HMA. POFA is a by-product of palm oil production. After combustion of solid waste from extraction of palm oil, about 5% POFA by weight of combusted material is produced (Tay, 1990). The color of POFA can range from light whitish grey to dark grey due to variations in un-burnt carbon content. Lighter shades of grey indicate low carbon content which in turn indicates high level of combustion, while darker shades indicate vice versa i.e. high carbon content, low rate of combustion (Abdullah et al. 2006).

Goh et al. (2006) suggested that POFA appears to be similar to fly ash. Fly ash consists of fine, glossy particles that are spherical in shape with some samples having hollow particles like plerospheres and cenospheres (Sharma et al. 2010). Similar physical features are observed in microscopic image of POFA taken by Tangchirapat et al. (2006) Furthermore, like fly ash (Sharma et al. 2010), POFA contains varying amounts of un-burnt carbon (Abdullah et al. 2006). In addition, comparison of chemical analysis of POFA and fly ash show rich in siliceous compounds, indicating their pozzolanic nature (ASTM C618). They have both been proven to be adequate as partial replacements of OPC in concrete (Tay, 1990; Tonnayopas et al. 2009). POFA's use in HMA has been studied by researchers such as Borhan et al. (2010) who found that replacing 5% of filler content with POFA does not impair performance properties of asphalt concrete mix. Furthermore, he found better stability values of samples modified with POFA. Modification with POFA also improved creep resistance and fatigue life of the asphalt concrete mix, while an increase in resilient modulus was also noted. Kamaluddin (2008) found that replacing stone dust with 100% POFA resulted in the highest improvement in the stability and stiffness values of Stone Mastic asphalt.

2. Materials and Methods

Shell Ltd supplied the 80/100-pen grade bitumen used in the study which is also widely used for paving applications in Malaysia and the POFA used in this study was collected from Seri Ulu Langat Palm Oil Mill Sdn Bhd. The ash was collected from the bottom of two different boilers (PFA and PFB), so that they have slightly different chemical properties. PFA was the darkest samples which reflected its higher carbon content and incomplete combustion. It was tagged as HCPF. PFC was the lightest in color, reflecting its low carbon content and greater level of combustion. Properties of the neat bitumen are shown in Table 1. It is important to mention aggregate gradation used conformed to the Malaysian Public Works Department guide and it is shown in Figure 1. Public Wrorks Department. (2007). In addition, OPC passing the 0.075 mm sieve was selected as the filler material.

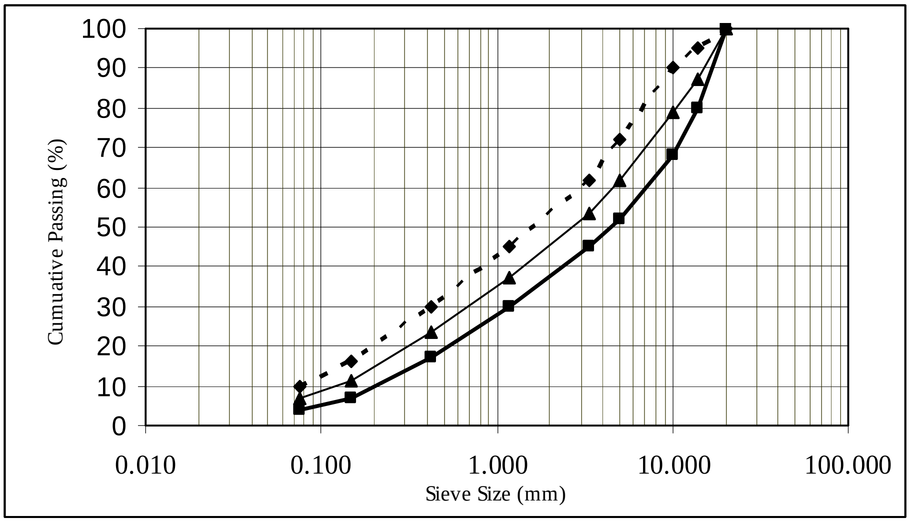

Fig. 1: Aggregate Gradation Limits for ACW14
(Source: JKR 1988)

Table 1: Physical Properties of Material Used

Property	Measured Parameter	Value
Bitumen (80/100)	Relative Density	1.02
	Softening Point (^oC)	44.0
	Penetration at 25^oC (dmm)	83
	Ductility (cm) at 25^oC	> 100
Aggregate	Specific Gravity	2.681

2.1 Marshall Stability Test

Marshall Stability test was carried out on compacted specimens at various bitumen contents according to ASTM D1559 (ASTM, 1999). The Marshall test is an empirical test in which cylindrical compacted specimens, 100 mm in diameter and approximately 63.5 mm in height are used. A water bath was prepared at a temperature of 60^oC and all specimens were immersed for 30 to 40 min in the water. The Marshall Stability testing machine was cleaned and set up to begin the test. After the specimens had been conditioned in the water bath, a load was then applied to the specimen at a constant rate (50mm/min) until failure, observing the flow and stability while loading. When the stability gauge reading reached its maximum and began to drop, the Marshall stability value (in kN) was noted as the deformation at the point of failure. All procedures met specifications as set by JKR/SPJ/2007, American Association of State Highway and Transportation Officials (AASHTO) and American Society of Testing and Materials (ASTM) unless specified. Marshall Mix Design was used to prepare samples conforming to JKR specifications for ACW14.

3. Results and Discussion

The Marshall method (ASTM D1559) was used to determine the optimal bitumen content (OBC) for conventional and modified asphalt mixtures. The results of the Marshall test are presented in Table 2. From this table, it can be seen that the high carbon POFA (HCPF) samples, after 30 minutes immersion in a water bath, have the highest Marshall stability values, followed by low carbon POFA (LCPF) and stone dust samples, respectively. Comparing the results of LCPF and stone dust, the difference between the Marshall stability values was not notably high. This might be due to the pozzolanic cementing nature of POFA. OBC of POFA modified samples was found to be higher than conventional HMA. This concurs with Kamaluddin’s (2008) study, who also found that OBC of SMA modified with POFA was higher than OBC of conventional SMA. The OBC of LCPF samples was found to be much higher than OBC for other mixes. This can be attributed to higher volume of filler in the sample, which has more surface area, thus more bitumen is required to coat the particles. On the other hand, optimum conditions for HCPF were at a bitumen content just a little higher than those for stone dust and much lower than OBC for LCPF. Since the major difference between HCPF and LCPF is the carbon content, it is possible that the high carbon content in HCPF acts as an asphalt extender. This would negate the absorbing properties of the POFA, thus reducing the OBC. The high stability and stiffness values of HCPF together with its economical OBC show that presence of high amount of un-burnt carbon was beneficial to the strength characteristics of the mix, but reduced the VFA.

Table 2. Physical and Mechanical Properties of ACW14 at OBC (%), Asphalt Institute Method

Filler	OBC (%)	Bulk Density (kg/m3)	VTM (%)	VMA (%)	VFA (%)	Stability (kg)	Flow (mm)	Stiffness (kg/mm)
JKR Specs	-	-	3 - 5	-	75 - 85	> 500	> 2.0	> 250
Stone Dust	5.6	2366	3.3	15.5	79.2	1524	4.8	317.25
LCPF	6.2	2340	3.8	17.0	78.1	1566	4.7	331.14
HCPF	5.7	2329	4.8	17.0	72.4	1711	4.5	383.81

3.1 Bulk Density

The use of POFA resulted in a decrease in the bulk density of the modified samples as seen from Figure 2. Bulk densities of samples made with POFA have lesser values than bulk densities of samples made with stone dust. This can be explained by POFA's lighter weight as compared to stone dust filler. During mixing it was noted that 60g of POFA occupied almost 2 times more volume than 60g of stone dust. Even at their OBC's, POFA modified samples have lower bulk density than conventional HMA samples. More filler volume in the mix would provide more contact points for the aggregate, which, according to Puzinauskas (1969) can be beneficial to the mix. These additional contact points may also contribute to higher shear strength.

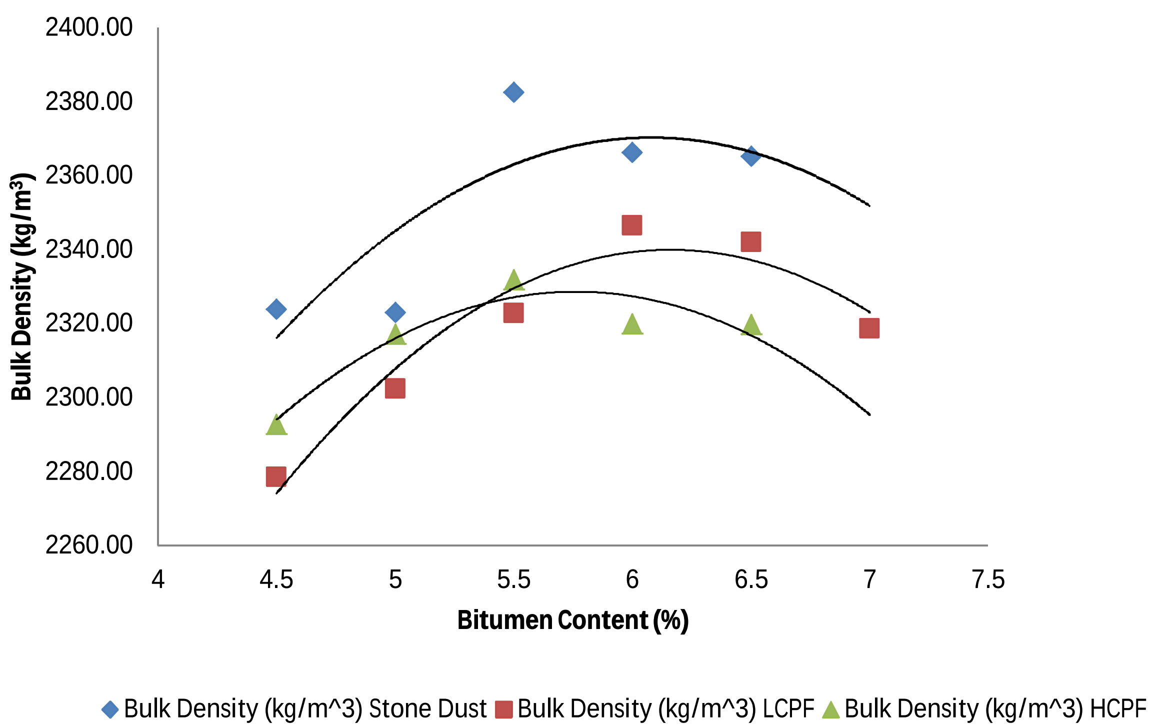

Fig. 2: Variation of Bulk Density of LCPF, HCPF Mixtures and Control Mixtures Prepared at Different Bitumen Content

3.2 Void Analysis

POFA modified samples have VTM within JKR limits, however when compared to the control specimens, the VTM is markedly higher (Fig. 3). Also HCPF samples had slightly higher VTM (1% at OBC) than LCPF samples. POFA also caused an increase in the VMA of the samples. The VFA value of LCPF samples is well within the JKR limit; however, for HCPF samples, the results show voids are not sufficiently filled with asphalt. This implies the asphalt film around the aggregate is thinner than required. This could lead to accelerated cracking and aging of the pavement.

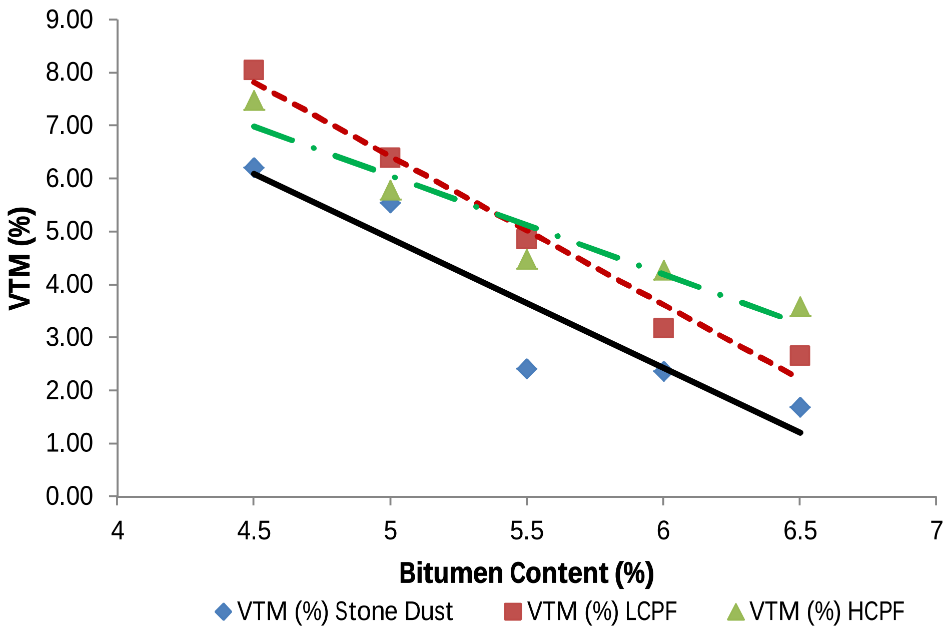

Fig. 3: Variation of VTM of LCPF, HCPF Mixtures and Control Mixtures Prepared at Different Bitumen Content

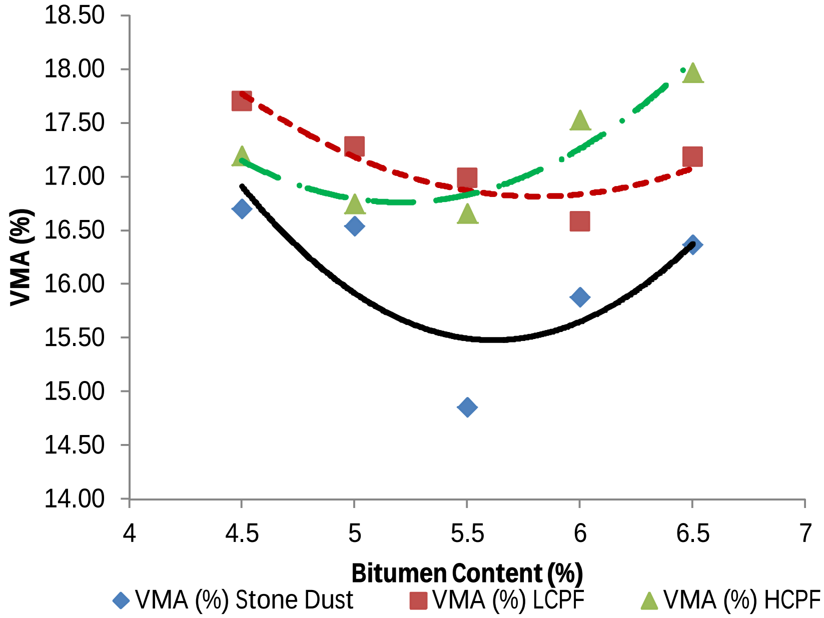

Fig. 4: Variation of VMA of LCPF, HCPF Mixtures and Control Mixtures Prepared at Different Bitumen Content

3.3 Stability of the Mix

Overall, HMA samples modified with POFA exhibited better stability and stiffness than conventional HMA. These concur with findings of Borhan et al. (2010) who found higher stability values of samples modified with POFA. Kamaluddin (2008) also found that using 100% POFA as filler in SMA gave the best stability and flow values. HCPF modified samples exhibited the highest stability values at a flow slightly lower than other mixes. This contributed to its high stiffness. Presence of LCPF in HMA was also beneficial to the stability and stiffness of the mix, returning better values than conventional HMA.

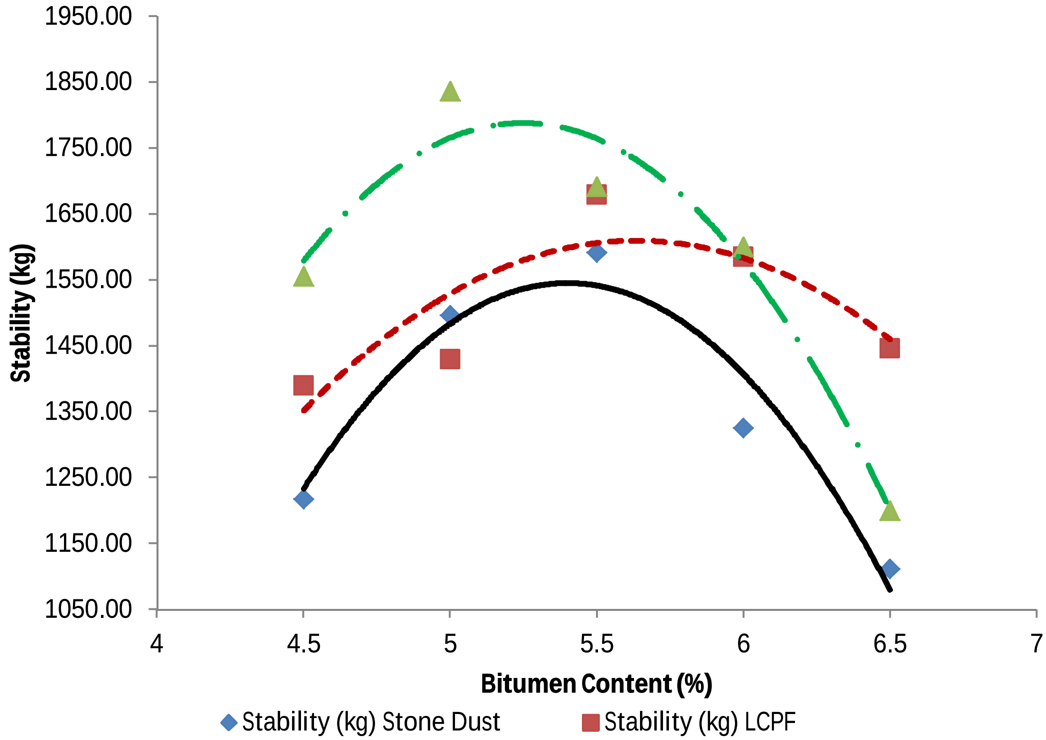

Fig. 5: Variation of Stability of LCPF, HCPF Mixtures and Control Mixtures Prepared at Different Bitumen Content

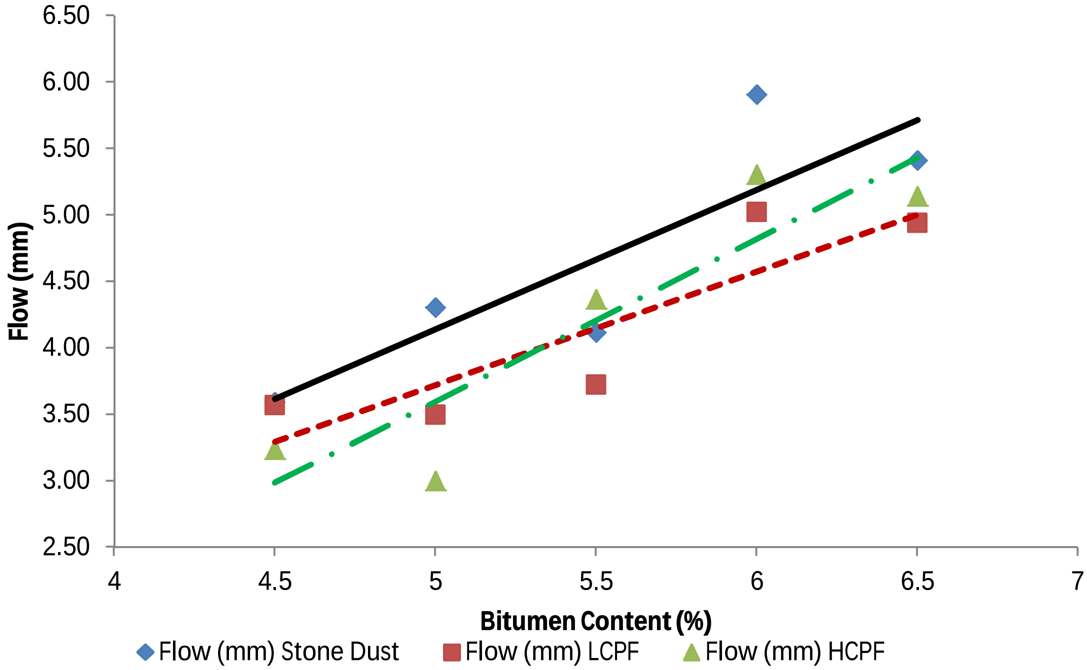

Fig. 6: Variation of Flow of LCPF, HCPF Mixtures and Control Mixtures Prepared at Different Bitumen Content

4. Conclusions of the Study

Evaluation of POFA in HMA has shown promising results in improving engineering properties of the mix. Processing of POFA uses technology already in use in HMA plants (e.g. sieving equipment). Other major changes during production will not be required since equipment that handles stone dust can handle POFA. Only changes required will be in the storage and handling sections. Larger container will be required to accommodate the larger volumes. Storage areas should be relocated away from sources of ignition to prevent the residual carbon from catching fire. Testing stage did not require any changes in equipment or procedure. Additionally, POFA is an abundant waste product in Malaysia and other palm oil producing countries. It is likely to be sufficient to meet demands. Collection of POFA is inexpensive and because it is light and available at Palm Oil mills all around Malaysia, its transportation is likely to be easy and cheap. Also, since no change in production equipment is required, its use can be implemented relatively cheaply. POFA can be successfully incorporated as mineral filler in HMA without degrading the engineering properties of the mix. POFA with high carbon content greatly improves the Stability and Stiffness of the mix without a significant increase in OBC, but gives a low VFA value. POFA with low carbon content also gives better Stability and Stiffness but requires greater asphalt content at optimum conditions, thus making it uneconomical. POFA successfully addresses some of the engineering, economic and environmental concerns of incorporating waste materials into HMA.

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