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Study on the Performance of Waste Materials in Hot Mix Asphalt Concrete

Rillagoda G.N.Yasanthi[a]*, Terrance M.Rengarasu[b],W.M.K.R.T.W.Bandara[c]

[a,b,c]*Department of Civil and Environmental Engineering, University of Ruhuna, Galle, 80000, Sri Lanka*

[a]*Email: navoda@cee.ruh.ac.lk*

[b]*Email: rengarasu@cee.ruh.ac.lk*

[c]*Email: wasala@cee.ruh.ac.lk*

Abstract

This study attempts to examine the behavior of Hot Mix Asphalt (HMA) concrete when selected waste materials, namely carbonized wood saw dust, PET and hot mix asphalt waste, are introduced and recommend suitable replacement percentages. The recommended replacement and addition rates were established by considering the Marshall properties. The results of the study reveal that, the wood saw dust carbonized in oxygen-less condition can be used to replace the traditional filler in HMA concrete up-to 2.74% of the total aggregate weight. In this study PET fibers of 30 mm length were used and up-to 2% of the total aggregate weight Marshall Properties showed an increasing trend. As the third part of the study old HMA concrete removed from 2 year old highway was tested suitability. With addition of reduced amount of bitumen satisfactory Marshall Properties were achieved. The cost reductions of 9.5% and 16.6%, compared to HMA made from virgin materials, were achieved for the case of adding carbonized wood saw dust and reusing HMA waste respectively. Cost and the additional bitumen needed for the reusing HMA waste should be based on the characteristics of the HMA waste sample.

Keywords: Hot Mix Asphalt; Waste Materials; Marshall Stability; Marshall Flow; Filler.

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* Corresponding author.

1. Introduction

Municipal solid waste generation in Sri Lanka is increasing. Estimated municipal solid waste generation in Sri Lanka was 0.89 kg/cap/day in year 1999 and the prediction for 2025 is 1.0 kg/cap/day [1]. Many local government bodies are struggling with the volume of municipal solid waste. Reusing is one of the most convenient and economical way of disposing solid waste materials. With ever diminishing material supply and increasing prices, there has been a renewed interest in reusing the waste materials in many fields of construction.

Considerable amount of literature has been published on reuse of solid waste materials as raw materials in Hot Mix Asphalt Concrete (HMAC). Generally, there are three ways to introduce waste material into HMAC. One advent is to introduce the waste material as a modifier to the asphalt binder. Studies have shown that, when asphalt binder is modified with addition of rubber, polymer and many other waste materials, HMAC exhibit better properties [2, 3, 4, 5].

The second advancement is replacement of traditional aggregates of HMAC with solid waste material. Conclusions from several studies confess the importance of the filler used in asphalt concrete [6, 7, 8]. Furthermore, it is globally accepted that the natural filler can be replaced with any suitable material either natural or artificial [9]. Usage of fly ash as filler in asphalt concrete dates back to 1950's. Authors in [10] discovered that fly ash act as a good filler. In recent history, many studies tested the suitability of fly ash in terms of mechanical properties of the mix and ended up with positive results upon reusing [9, 11, 12]. Other waste materials which are proven to give satisfactory results in asphalt concrete are, glass [13], recycled concrete aggregates [14, 15], steel slag [16], scraped tires and plastics [17], construction and demolition waste [18] and asphalt waste [19, 20, 21]. The third method is to use additives such as polymers and fibers to HMAC in addition to the binders and aggregates. The performance of HMAC with PET and HDP in stone mastic asphalt were tested in many studies [22, 23, 24, 25, 26]. The results reveal that the replacement or addition makes the mix better.

Reuse of agricultural wastes in HMAC is of high interest to an agricultural countries. In similar studies, [27], [28] and [29] suggest that Carbonized Rice Husk (CRH) is suitable to be used as a partial replacement of the filler used in an asphalt mix. Authors in [30] studied the effect of saw dust used as the filler in hot rolled asphalt system.

Although many material have been tested and proven to be useful replacements and additives to HMAC, such material do no not make the bulk of the solid waste in agriculture based countries like Sri Lanka. This study aims to introduce solid waste materials, more prevalent solid waste in Sri Lanka, as replacements and additives in HMAC. There are two objectives, where the first is to determine cost savings by replacements and additives in HMAC, and the second objective is to determine the optimum binder content needed for HMAC with replacements or additive.

2. Methodology

Standard Marshall Test procedure was used in this study. The bitumen percentage is varied from 4% to 6% in

0.5% intervals. The optimum binder content was established considering the optimum binder contents corresponding to the Marshall stability, the specific gravity and the median of designed limit of percent air voids in the total mix.

2.1. Materials

Bitumen of penetration grade 60/70 was used as the binder. Crushed rock with a nominal size of 20mm was used as the coarse aggregate and chipped rocks of nominal size of 14 mm was used as the fine aggregate. Stone dust was used as the conventional filler.

Figure 1: Saw Dust Ash (SDA)

Three solid waste materials were tested in this study. First is 'carbonized saw dust' obtained from Albesia (*Albizia Julibrissin*), by burning it in a sealed oxygen-less incinerator (Figure 1) and sieved using No.8 sieve (2.36mm). Second is the 'PET fibers' having a diameter of 1 mm and with a specific gravity of 1.2 (Figure 2). Third is the ‘scraped wearing course’ from old road surface (Figure 3).

Figure 2: Polyethylene Terephthalate (PET)

Figure 3: Asphalt waste

2.2. Sample Preparation

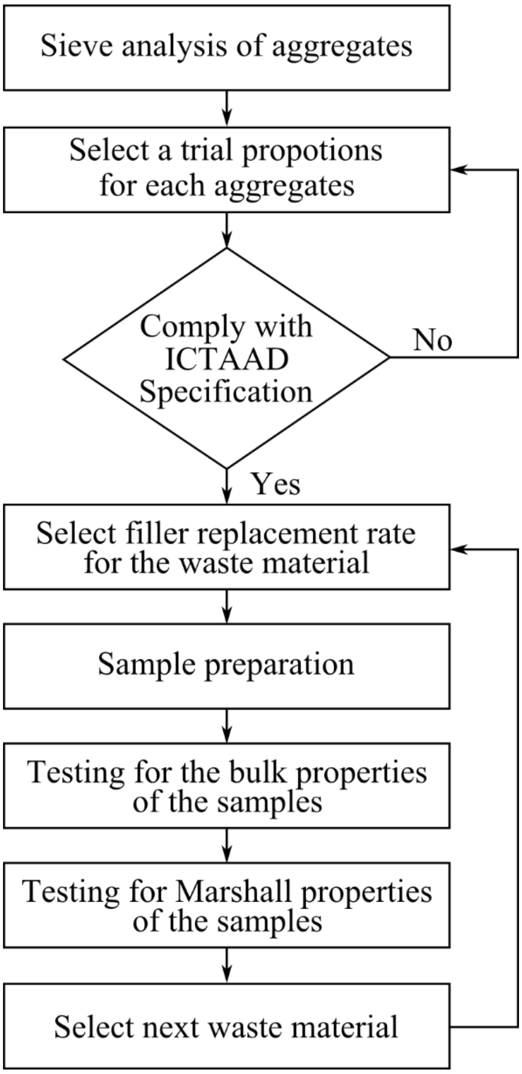


Figure 4: Flow chart for methodology

The grading requirements used were based on CIDA specification. In terms of Saw Dust Ash (SDA), the filler replacement rates were 4.87% and 2.74% of SDA from the total aggregate weight of the mix (1200g). The replaced saw dust ash weights were calculated such that equal volumes of saw dust ash and stone dust will be subjected to the replacement. Therefore, 50g and 30g of saw dust ash were used in the mix. Polyethylene Terephthalate (PET) fiber was tested based on the variation of length of fiber. Additionally, the variation of the properties were monitored for different PET weights. PET was introduced to the mix before bitumen is poured to the mix. For asphalt waste, the spoil waste sample contained an inherent bitumen percentage of 1.77% from the total weight. Therefore, a bitumen weight of 4.25g was reduced from the bitumen added for all the samples cast with asphalt waste. With the results of the combined grading of the existing aggregates, the mix proportion was decided. All samples were cast with the mix proportion of 25%, 5%, 50% and 20% from coarse aggregate, fine aggregate, filler and the spoil waste sample respectively. The overall process followed during the study is presented in a flow chart in Figure 4.

3. Results and discussion

3.1. Material properties

The specific gravities of the raw materials used throughout the study are presented in Table 1.

Table 1: Specific gravities of materials

Aggregate Type	Specific Gravity(SSD)	Apparent Specific Gravity
Coarse Aggregate	2.648	2.27
Fine Aggregate	2.296	2.74
Stone Dust	2.506	2.64
Saw Dust Ash	-	0.586
Bitumen	-	0.979

3.2. Marshall properties

- SDA added samples

The variation of Marshall Stability for the control sample and the SDA added samples is graphically represented in Figure 5. The Marshall stability recorded for the SDA added samples is low compared to the control sample. However, in higher SDA contents, the samples did not meet the minimum standard for the high traffic load (8kN). The aggregate surface texture in the SDA added samples is made soft and silky by the addition of tiny SDA particles to the mix. It reduces the strength in the SDA added samples in comparison with the control sample. Apart from that, the SDA particles tend to absorb part of the bitumen introduced to the mix. After being saturated, the rest of the bitumen added are acting as the binder to tie up the aggregate skeleton. It leads the thickness of the bitumen film on the surface of aggregates to be reduced. Hence, the total bitumen content has to be increased in order to increase the effective bitumen content which is available to act as the bonding agent.

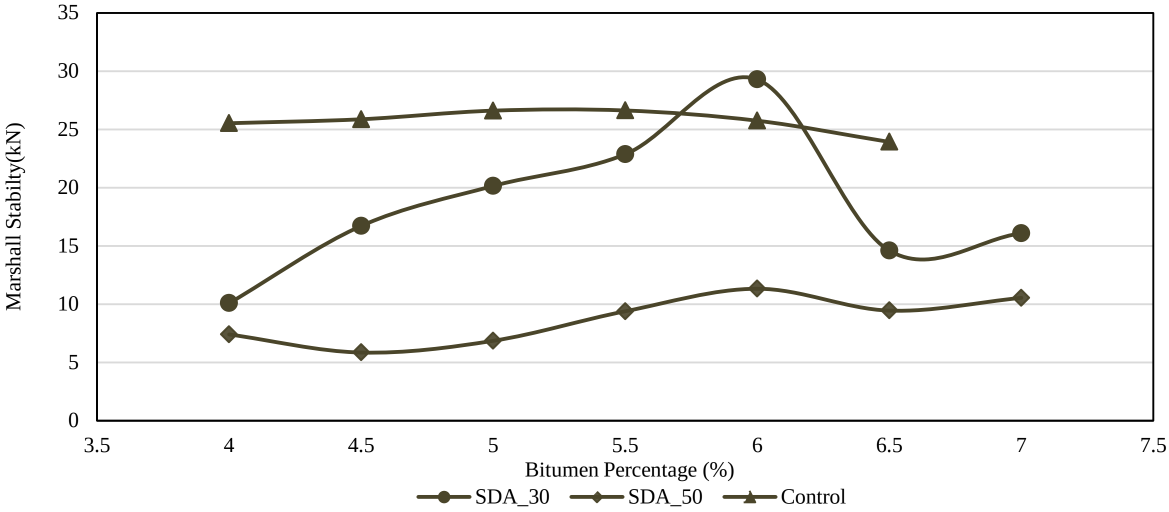


Figure 5: Variation of Marshall Stability with Bitumen Percentage for Control and SDA samples

However, the maximum stability was recorded for the samples with 30g of SDA and the value was even higher compared to the value recorded for the control sample. In the SDA added samples, the cracks in the coarser aggregates are filled with the tiny SDA particles. Additionally, the SDA particles rest on the surface of the aggregates. Apart from that, the SDA particles resting on the aggregate surfaces form an additional bitumen film because of the absorption abilities of the SDA particles. Therefore, a strong bitumen film is resulted and hence, the bonding ability is increased. However, with the increase of the SDA content, the removed filler weight is increased proportionately. In order to introduce 50g of SDA to the mix, 224g of filler should be removed. Therefore, the total weight of the filler in the mix is 546g, in which 496g is the conventional filler. Eventually, the replacement results in a decrease in the ability of packing and tightening of the aggregate skeleton. As a result, the strength is reduced when the sample is subjected to loading.

The Marshall Flow is varied parallel to the variation of Marshall Flow of the control sample for lower SDA contents (Figure 6). However, the Marshall Flow keeps increasing with the SDA content used. A considerable amount of the conventional filler is replaced when the used SDA amount is 50g. It leads the inter particle bonds between the aggregates to be weaker. Hence, the flow is increased considerably for samples with a higher SDA weight.

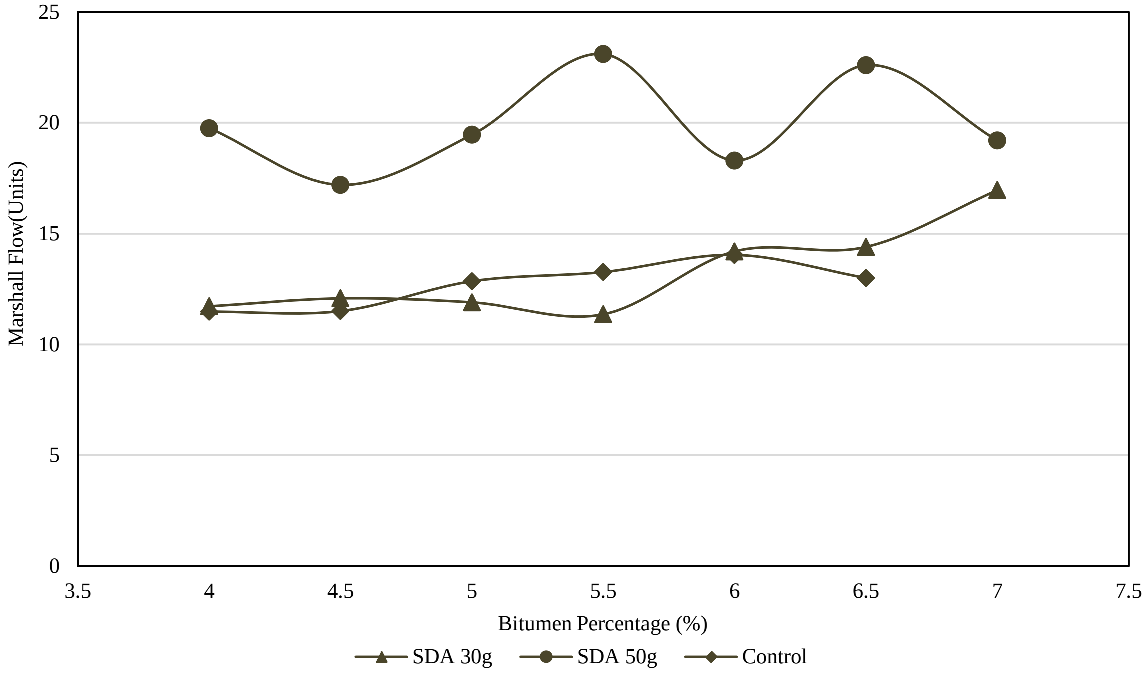


Figure 6: Variation of Marshall Flow with Bitumen Percentage for Control and SDA samples

- PET added samples

PET was studied in terms of the length of the fibers and the added weight. Any category tested did not exhibit a well-defined variation either in Marshall Stability or Marshall Flow. With the absence of a definite trend in the Marshall Stability and Flow, the Marshall Quotient was used to deduce the recommendations. The variation of

Marshall Stability, Flow and Marshall Quotient are graphically represented in Figure 7, 8 and 9 respectively.

During the introduction of PET fibers to the mix, a portion of the added PET fibers is melted. The melted portion act as a bonding agent, increasing the cohesion. The left PET portion with solid PET fibers act as a reinforcement, supporting the aggregate skeleton to bear the load. As a result, the load carrying capacity measured by the Marshall Stability is increased in PET added samples.

The Marshal Flow also follows an ambiguous variation. The standard flow value for road construction (8 to 18 units) is not met by some samples cast with PET fibers. The PET fibers are sticky in nature. Therefore, the melted part causes the samples to shrink more resulting higher deformations. Withal, the remaining PET fibers cause the aggregates slip due to the soft surface texture and the cylindrical shape of the PET fibers. Hence, the flow values are increased as a result of both components existing in the samples. The Marshall flow is increased with the PET content added. Almost all the control sample flow values are recorded below the flow values of the PET added samples.

In terms of the Marshall Quotient, samples with 4% bitumen and 3cm long PET fibers recorded lower values than the minimum standard values for high traffic loads (0.5). In general, all the Marshall Quotient values are low compared to the respective values in the control sample.

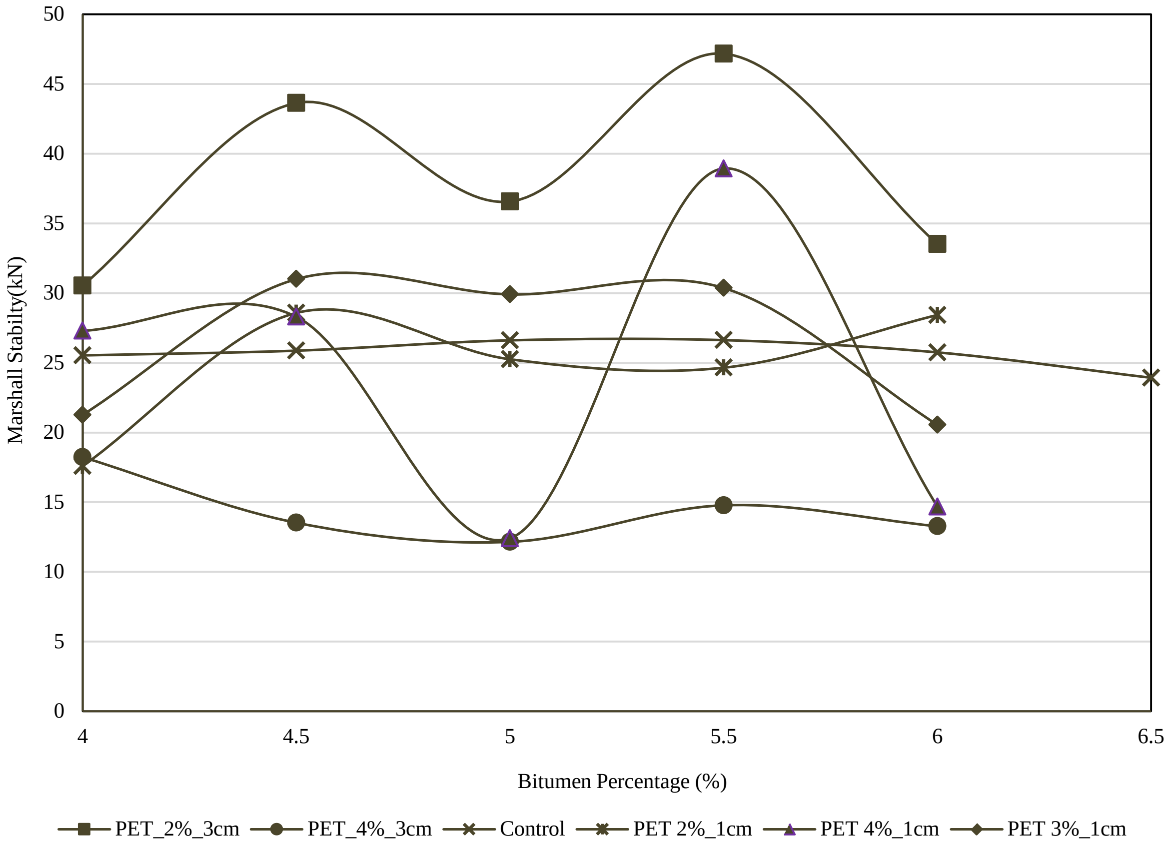


Figure 7: Variation of Marshall Stability for samples with PET

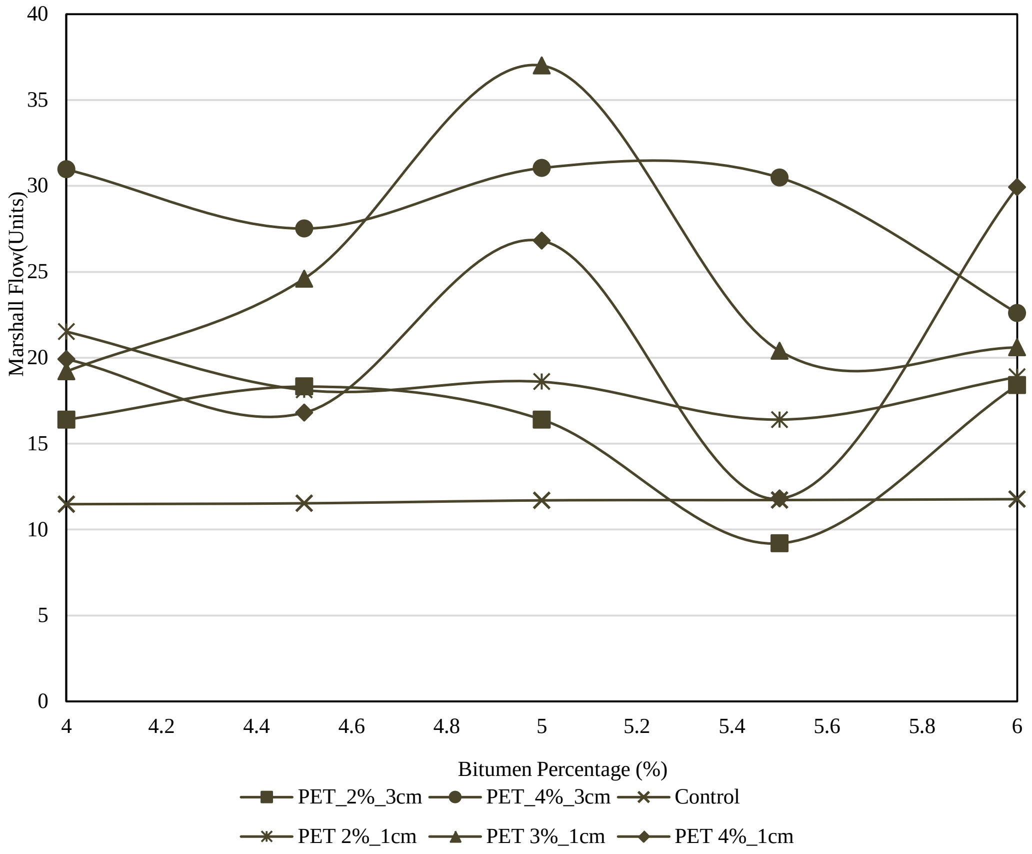
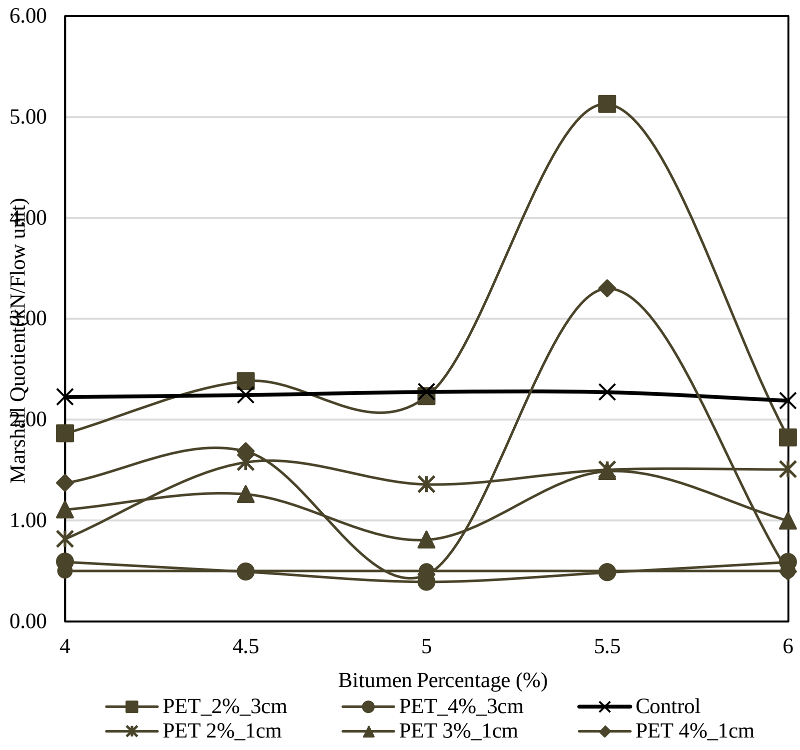


Figure 8: Variation of Marshall Flow for samples with PET



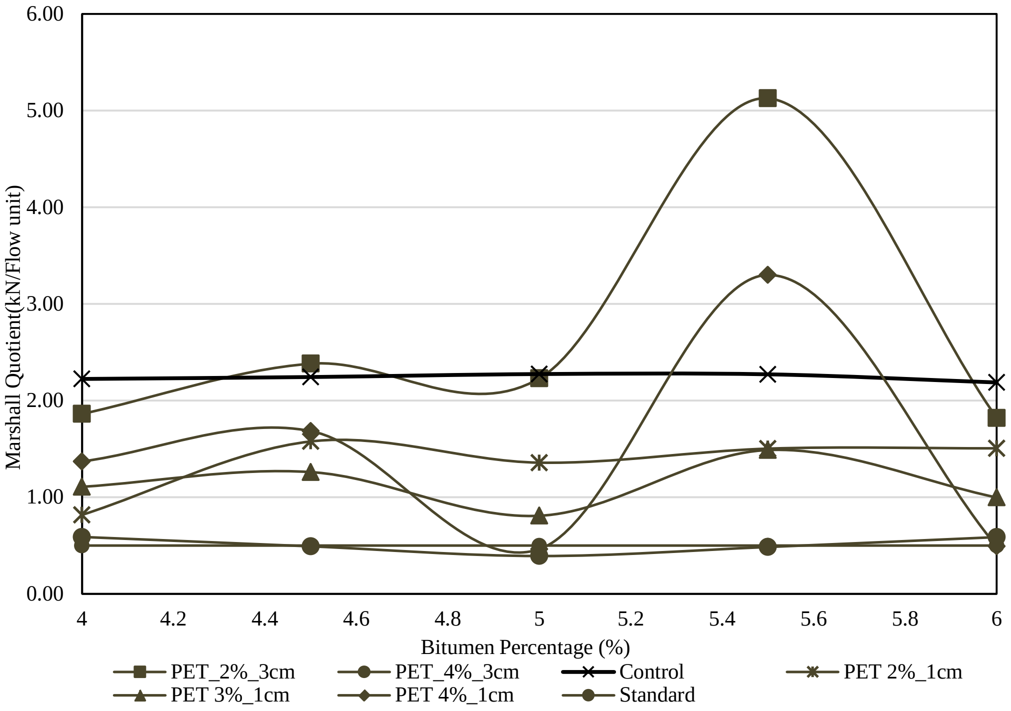


Figure 9: Variation of Marshall Quotient for samples with PET

- Asphalt Waste added samples

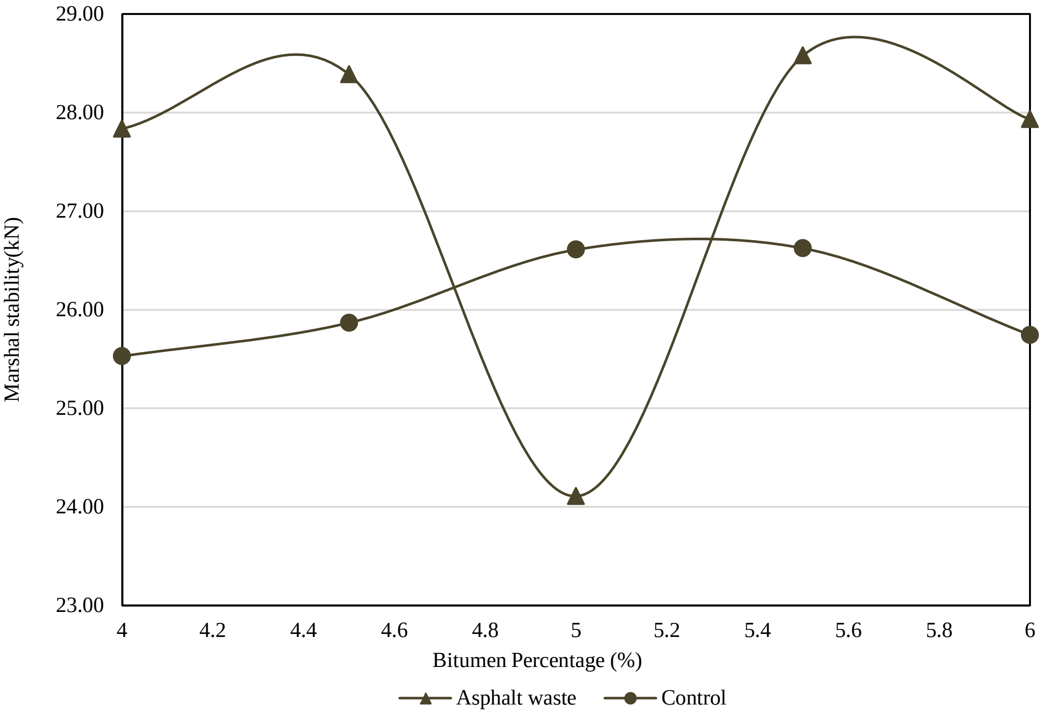


Figure 10: Variation of Marshall Stability with Asphalt Waste

The variation of the Marshall Stability with Asphalt waste added samples is graphically represented in Figure 10. The replacement of virgin raw materials with the asphalt waste materials resulted an increase in the Marshall Stability. The aggregates in the asphalt waste sample already contain a thin bitumen film coated to their surface. Therefore, the thickness of the bitumen film is increased in the new samples with asphalt waste. In the asphalt waste added samples, the inter particle bonds are made stronger. Withal, the cracks in the aggregate surface of the asphalt waste portion are already filled by the inherent bitumen portion. It allows the bitumen added to totally contribute to tie up the aggregates. Eventually, the asphalt waste added samples exhibit higher Marshall Stability values.

In terms of Marshall flow, the variation is parallel to the control sample (Figure 11). However, the values liebelow the respective values of the control sample. When the asphalt waste is introduced as a part of the aggregates, the inter particle bonds are strengthen. The spoil sample contains aggregates which are used previously. Therefore, the packing of the aggregates is well defined. With the load application, the aggregates in the samples tend to rearrange and pack leading lower deformations. Yet, the Marshall flow values resulted are lower for the asphalt waste added samples compared to the control.

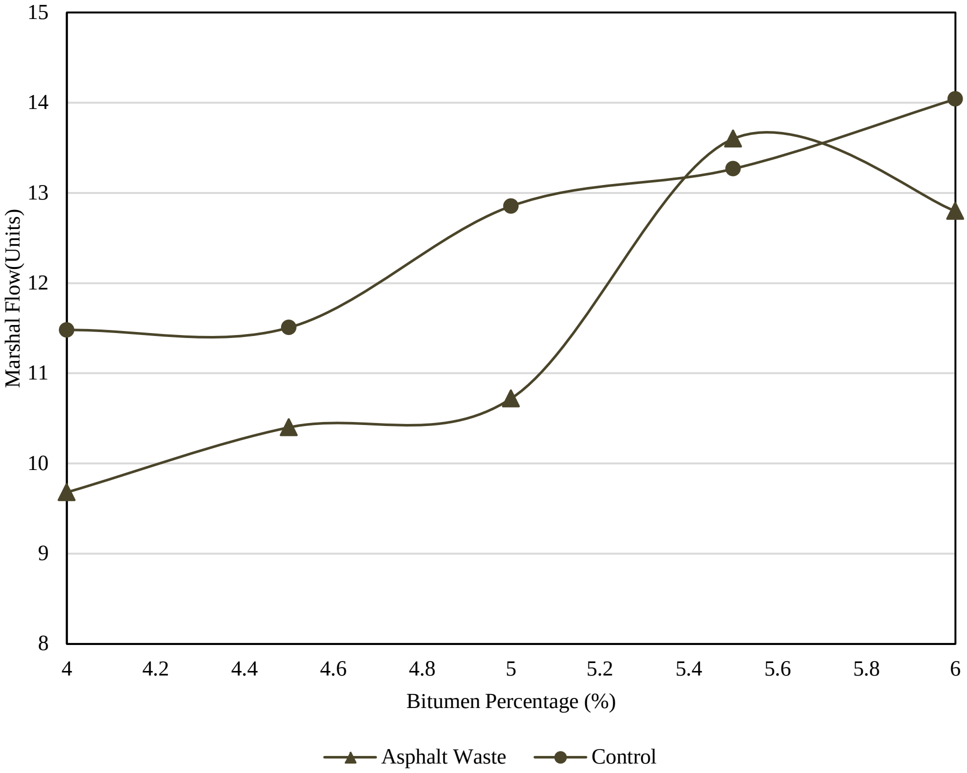


Figure 11: Variation of Marshall Flow with Asphalt Waste

3.3. Bulk properties

The optimum binder content and the average specific gravity of the samples are tabulated in Table 2 and the variation of the two properties are graphically represented in Figure 12.

Table 2: Bulk properties of the samples

Waste material added	Optimum Binder Content	Average Specific Gravity
Control	5.28	2.29
SDA 30g	5.50	2.00
SDA 50g	5.20	1.79
PET 2% 1cm	4.87	2.19
PET 3% 1cm	4.70	2.17
PET 4% 1cm	5.00	2.17
PET 2% 3cm	5.03	2.23
PET 4% 3cm	4.67	2.11
Asphalt Waste	5.13	2.32

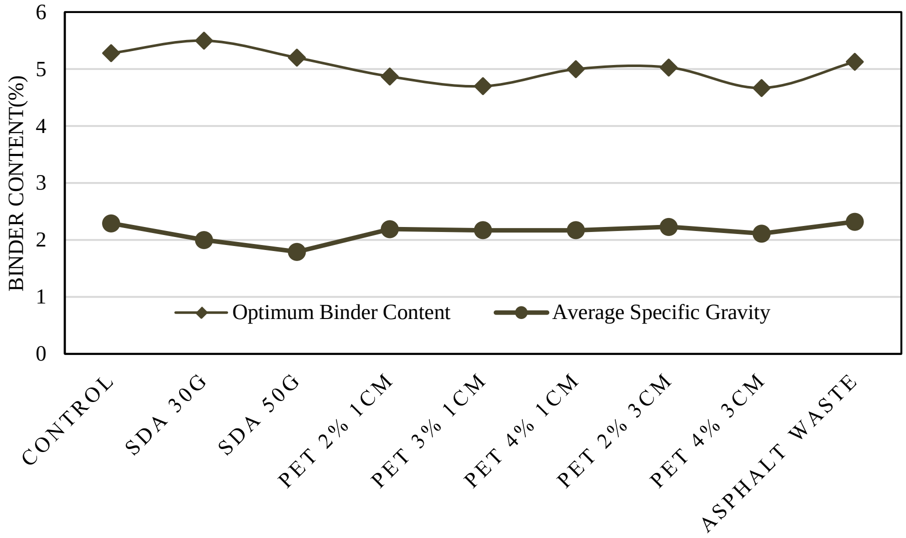


Figure 12: Variation of Bulk Properties for waste added samples

According to Figure 12, the optimum binder content is reduced when a waste material is introduced to the mix, except in samples with a higher SDA content. In terms of SDA added samples, both of the bulk properties are reduced with the SDA content added. SDA was added to the mix before the addition of the binder to the mix. Therefore, the SDA particles are well mixed with the aggregates, filling the cracks on the coarser aggregate surfaces. With that, the quality of the aggregates is increased resulting a lower binder content. Apart from the bulk properties examined, the water absorption rates in the control and SDA added samples was monitored. The variation of the water absorption and other physical properties are graphically interpreted in Figure 13 and Figure 14. Two samples with 30g of SDA as aggregates and 6% bitumen content in the asphalt mix were subjected to the comparison with a control sample having 6% bitumen content. According to the results, the water absorption resulted for SDA added samples is very high compared to the control sample. The increase in weight due to the introduction of water was 0.6% and 2% for control and samples with SDA, respectively. The higher water absorption resulted for the SDA added samples is identified to be due to two reasons. The first reason is the inherent absorbing ability of the SDA particles. SDA was collected as the residue of the anoxic burining of saw dust. Saw dust is originally an agricultural element. On the other hand, the sealed burning in an incinerator leaves pure carbon residue as the SDA. It leads the SDA added samples to absorb more water. The next reason for such an increase in water absorption is identified to be due to the other bulk properties resulted for the SDA added samples. The Voids in Mineral Aggregates (VMA) resulted for the SDA added samples is high compared to the control sample (Figure 14). However, the Voids Filled with Bitumen (VFB) is lower for the SDA added samples compared to the control sample. Eventually, the explanation indicates that more voids are present in the SDA added samples, where most of the voids are left as air voids. A larger portion of the air voids are escaped being filled with bitumen in the SDA added samples. Therefore, more air pockets are waiting for water. When water is introduced, the extra air pockets in SDA added samples are filled with bitumen. In control sample, there are less voids unfilled. Eventually, the water absorption is higher in samples cast with SDA.

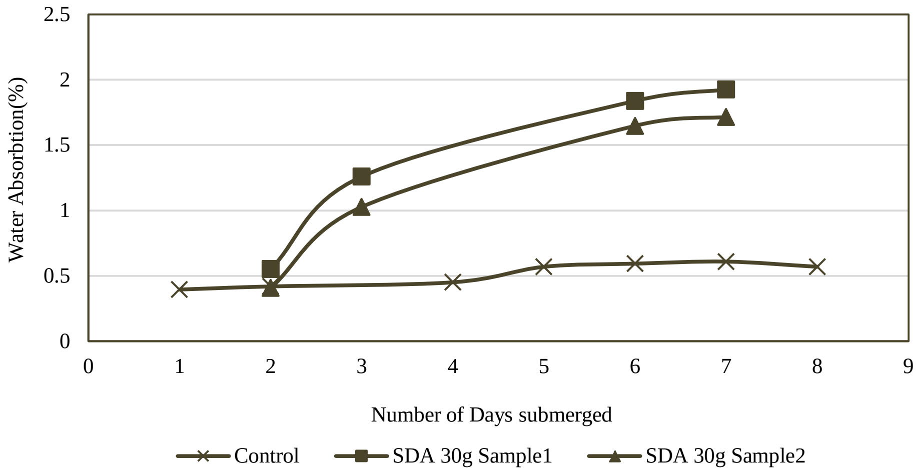


Figure 13: Water absorption patterns for control and SDA added samples

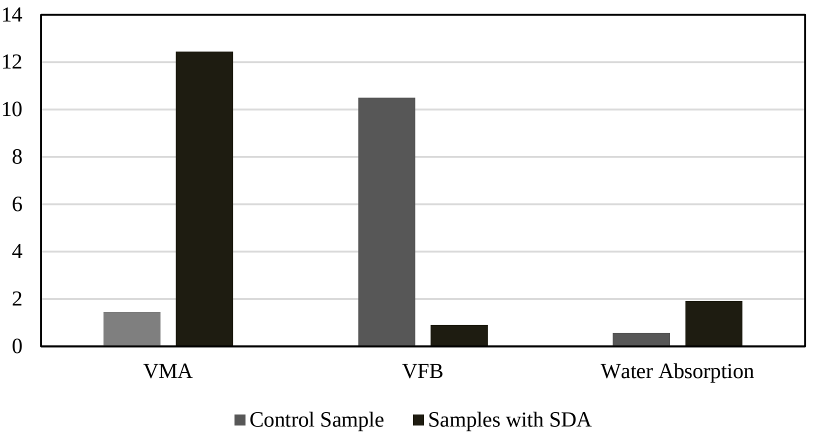


Figure 14: Variation of the bulk properties of samples

In terms of PET added samples, the variation in the optimum binder content does not follow a definite trend. It is identified to be due to the melting of the PET fibres during the addition to the mix. The PET fibres were mixed prior addition of the binder. Therefore, a portion of the PET fibres are melted due to the high temperature in asphalt production. The melted portion is not predefined and it is not quantifiable. Therefore, the variation follows a random trend. However, the left PET fibres were clearly visible on the surface of the samples. Figure 15 is a capture of a sample with 3cm long PET fibres and a 5.5% bitumen percentage of total weight of sample excluding PET weight.

Figure 15: Sample with PET fibers

For asphalt waste added samples, the optimum binder content and the average specific gravity vary inline with the control sample. A large deviation is not monitored because the asphalt waste sample also contain similar characteristics to the mix design used in the study.

4. Conclusion

In terms of saw dust, a saw dust ash content of about 3% from the total aggregate weight of the mix including the saw dust weight. The saw dust used should be burnt in an anoxic environment in order to prevent the type of wood used affecting the properties of the mix. Although the strength and the durability are prominent, the water absorption should be strictly monitored further. By replacing the conventional filler used in an asphalt mix with saw dust, the cost of asphalt construction can be reduced about 9.5% from the original cost. For PET, the recommended weight is 2% of the total aggregate weight and the length of PET fibers recommended is 3cm. Asphalt waste is recommended to be reused in asphalt construction. The mix proportions and the reused amount of asphalt waste should be determined considering the characteristics of the particular waste sample. When asphalt waste is used, the cost can be reduced about 16.6% from the original cost of construction of asphalt. Ultimately, all the waste materials tested can be reused as either an aggregate or an additive to asphalt concrete. Among the waste materials tested, the best performance was achieved by asphalt waste.

5. Limitations and Recommendations

The study was carried out for saw dust belonging to Albesia (Albizia Julibrissin). The saw dust collected was first burnt in an anoxic condition, with the purpose of extracting the pure carbon residue. It allows any type of saw dust to be used in practical application. However, the variation of the results with different sources of saw dust was not monitored during the study. Therefore, further research is recommended to identify the differences with other types of saw dust origins. According to the study, the water absorption is respectively high, when saw dust is introduced to the asphalt mix. In order to use saw dust in real time application, the consequences of the long term water absorption should further be monitored. On the other hand, the experiment introduces a novel method of capturing carbon. By storing the carbon atoms in flexible pavements, carbon capturing is performed. It realizes environmental benefits. However, the captured carbon might escape back to the environment. This phenomenon will take effect after a certain period of time, when the carbon in SDA reacts with the oxygen in atmosphere and released as Carbon Dioxide. However, further research on the time for the carbon to escape is recommended as a future direction of this study.

The study was carried out for flexible pavements with medium traffic loads, represented by 50 numbers of standard blows in the Marshall casting procedure. Therefore, the results of the study can be used for roads with a low or medium traffic. However, most of the results satisfy the corresponding limits for high traffic loads also. Yet, it is important to conduct further research on the applicability of the results of the study, prior using them in real time application.

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