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Performance of asphalt mixture incorporated with tin ore tailing

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Abstract. Tin Ore tailings (TOT) are waste generated from tin mining activities, which not only occupy lots of land, but also result in severe pollution to the surroundings. Many studies by researchers exploring better ways to increase the usage of industrial by-products in order to ease disposal problems preserve natural sources and save the environment. In this study, 1%, 3% and 5% of TOT are incorporated with ACW14 mixture in accordance to JKR 2008. 5% optimum bitumen is used for all samples. Marshall Mix design test is conducted to determine the volumetric properties, stability and flow. Moisture susceptibility test conducted to determine the indirect tensile strength in dry and wet samples. Generally, the stability values increases with the percentage of TOT increased.

1. Introduction

Tin mining in Malaysia have been around since 1800s and today the increasing use of tin in electronic industries increases the tin production. Malaysia have accumulated 113,700 hectors of tin tailings posing threats to environment and safety of living organic. The problem statement to this study is with the TOT in abundance which poses environmental threats and with no economic benefits, these tailings requires waste management [1-4]. With the increasing environmental awareness and the encouragement of sustainable development, the road construction industry have many studies done in utilising mine tailings with successful results. This allow the possible prospect of utilising TOT in pavement. Unlike other industrial by-products such as iron ore tailings and copper mine tailings that are often utilised in different industry such as in building construction and road construction, few studies have done to use TOT except for its use as refractory bricks and in rigid pavements that both have shown positive results. Utilising tin tailings road construction may be one of the solution to manage and reduce the mining wastage. This study will investigate the performance of TOT in asphalt mixture. The research objective is to apply different percentages of TOT in asphalt mixture and evaluate the performance with Marshall Test and moisture susceptibility test and to analyse the performance of asphalt mixture blends and determine the suitable percentage of tin ore tailing for the asphalt mixture. Wang et al. [2] studied that magnetite tailings can significantly improve the high temperature property and enhance the anti-rutting property of the asphalt mixtures due to the angularity and higher crushing value in contrasted to limestones. A study by Oluwasola et al. [3] with replacing 20% of fine aggregates with copper tailings ACW14 with bitumen grade 80-100 shows O.B.C of 5.06%, higher air void, bulk specific gravity, stability and stiffness compared to conventional mix. Flow and VMA is slightly lower than conventional mix. The indirect tensile strength of mix with copper tailings show to be higher than normal mix. Vasudevan et al. [5] studied on the use of coal bottom ash in ACW14 with 5.1% bitumen grade of 60/70 shows that the optimum content of coal bottom ash is 1% with density slightly lower than normal mix, higher stability and lower flow values.

2. Methodology

2.1. Aggregate and binder

The aggregates are oven dried for 24 hours and sieved according to ACW14 wearing course gradation as according to JKR/SPJ/2008 [6]. Bitumen used with a penetration grade of 60/70 with penetration value 65dmm and softening point of 51°C. All samples are prepared with 5.0% optimum bitumen. Recommended bitumen content is 4-6% in JKR 2008. 5% of bitumen content used of weight of aggregate without TOT.

2.2. Tin Ore Tailing (TOT)

Tin ore tailing have a physical feature of fine dark brown sand with fine dusts. TOT was collected from a tin mining factory in Sungai Lembing, Pahang. TOT are oven dried for at least 4 hours and sieve analysis are conducted. TOT is classed to particle size of 0.075mm and less. TOT of 1%, 3% and 5% of aggregate weight will be added into the mix.

2.3. Aggregate gradation

Tin ore tailing have a physical feature of fine dark brown sand with fine dusts. TOT are oven dried for at least 4 hours and sieve analysis are conducted. TOT is classed to particle size of 0.075mm and less. Table 1 shows the aggregate gradation used according to specification in JKR/SPJ/rev2008. Figure 1 shows the sieve distribution of aggregates.

Table 1. Aggregate gradation for ACW14 [6]

Sieve size (mm)	Percentage passing by weight (%)	Selected gradation (%)	Percentage of weight of aggregate (%)
20	100	100	0
14	90-100	95	5
10	76-86	81	14
5	50-62	56	25
3.35	40-54	47	9
1.18	18-34	26	21
0.425	12-24	18	8
0.15	6-14	7	11
0.075	4-8	4	3
PAN		0	4
Total		-	100

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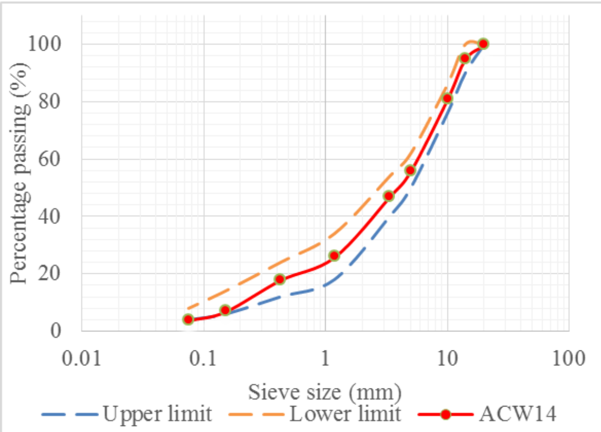

Figure 1. Sieve distribution of ACW14 aggregates

2.4. Sample preparation

A total of 36 samples are prepared in this study with ASTM-D1559. 3 samples are prepared for each type of mix. Samples are prepared by oven heat the aggregates in mould and bitumen. The aggregates are poured in mixing bowls and TOT is added before bitumen is poured. The sample is mixed at a maintained temperature of 140°C and the mix is poured into the mould in 3 layers. The samples are compacted 75 times on each side. The samples are allowed to cool, removed from sample extractor and kept for testing. The sample for 0%, 1%, 3% and 5% of TOT identified as control, TOT1, TOT3 and TOT5.

2.5. Volumetric properties

Samples are prepared and cooled at rom temperature. Average height of each samples are recorded by taking three height readings. Samples are then weighed on a balance. Then the samples are fully submerged in water at room temperature and the submerged weight are recorded. Then the sample is removed and the surface is dried with cloth and the SSD weight is recorded. The data will depict the relationship between the percentage of tin ore tailing with a dense, air voids, voids filled with bitumen, stability, flow, and stiffness.

2.6. Marshall Stability and flow test

Samples are prepared at a specific temperature by immersion in a water bath at a temperature of 60 °C ± 1 °C for 30 min. The samples are then placed in a Marshall Apparatus machine and loaded at a constant rate of deformation of 50.8 mm/min until the maximum load was reached. The stability result (in kN) was recorded by the Marshall Apparatus machine. The stability and flow value can be used to determine the Marshall Quotient (MQ). MQ can be used as a measure of the material's resistance to permanent deformation in service. A higher value of MQ indicates a stiffer mixture and indicates that the mixture is likely more resistant [7].

2.7. Moisture susceptibility test

Moisture susceptibility test is conducted according Modified Lottman test [8] procedure. The tensile strength of an HMA mix is generated by the cohesive strength of the asphalt binder and the bond strength at the binder-aggregate interface. The tensile strength is calculated from the maximum load the sample can undergo prior to cracking [9]. A cylindrical sample is loaded with vertical compressive loads; uniform tensile stress along the vertical diametrical plane will be generated. Failure occurs in the form of splitting along the loaded plane. Six samples of each mix types (3 for dry and 3 for wet) are prepared to air void contents of 6.5% and 7.5%. Three samples will be conditioned. The conditioned samples are first partially saturated with vacuum at a level between 55% and 80%. The samples submerged in a 60° water bath for 24 h. After that, the samples are removed and is submerged in a 25°C water bath for 2 h. The samples subjected to indirect tensile test and the maximum strength recorded. Tensile strength ratio is calculated by following equation:

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3. Results and discussions

3.1. Bulk density

Density shows smaller the volume of sample the higher the density whilst maintaining the weight of sample. Based on Figure 2 and Figure 3, the density of samples increases as the percentage of tin ore tailing incorporated in sample mix increases. The control sample shows to have the lowest bulk density at 2.25 g/mm while the highest density is sample mix with 5% of TOT at 2.96 g/mm. The highest bulk density was select according to recommendation by JKR 2008. This is the volume of air voids between the aggregate particles of a compacted mix. The graph depicts the small decrease in VTM as percentage of tin ore tailing increases. Small difference is seen between control and 1% of TOT with 6.86% and 6.83% respectively. The VTM of 5% TOT shows 5.30%. The recommended range is 3%-5% according to JKR 2008. High VTM can lead to durability problems and stripping while low VTM may result in bleeding, rutting and loss of mixture stability [10-13]. This shows 5% TOT is the suitable percentage to be added to 5% bitumen sample mix.

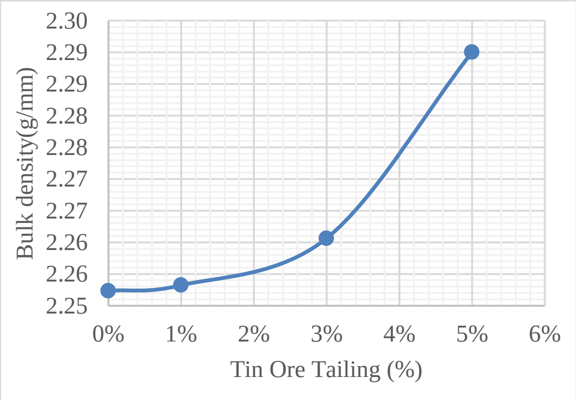

Figure 2. Graph of density versus percentage of Tin Ore Tailing

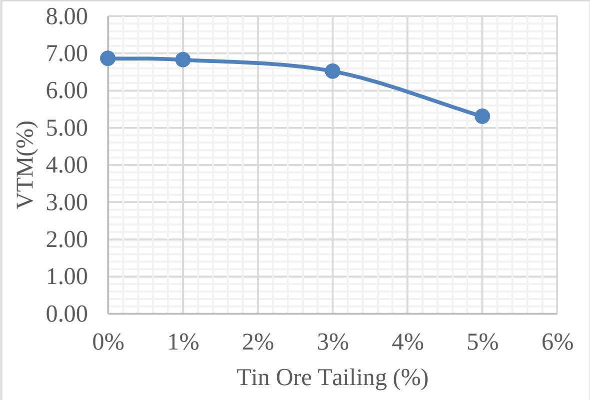

Figure 3. Graph of Void in Total Mix against percent of TOT

3.2. Voids Filled Bitumen (VFB)

VFB is the percentage of the void of aggregate that filled with asphalt. Figure 4 illustrates the gradual increase of VFB with percentage of TOT. The lowest VFB from control sample with 61.43% while the highest is from 5% TOT sample with 67.7% VFB. This is due to small particle size of TOT are mixed with bitumen and are able to fill the voids between aggregates and therefore reduces the voids which are not filled with bitumen.

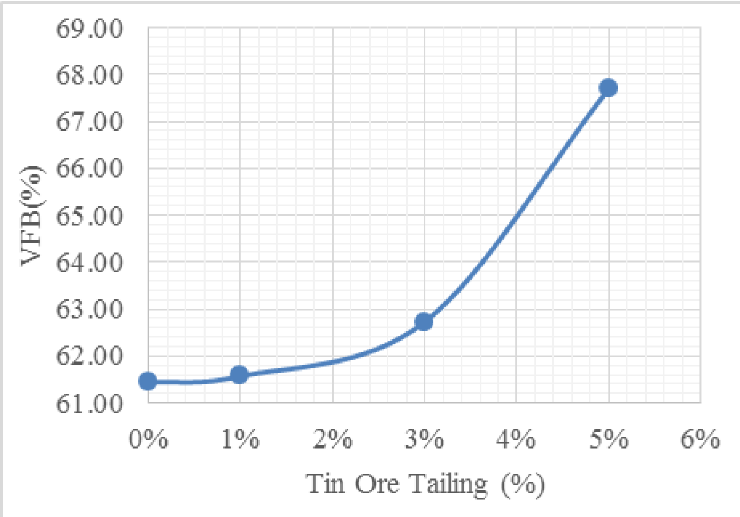

Figure 4. Voids filled with bitumen versus percentage of TOT

3.3. Flow

The flow generally shows a decreasing trend as the percentage of TOT increases (Figure 5). Lower flow indicates that a pavement is stronger as the addition of TOT allow improvement of interlocking between particles which will reduce deformation. JKR 2008 recommends flow between 2mm-4mm. Although the data does not fall within the range but the addition of TOT shows the possibility of reducing the flow value in mixture.

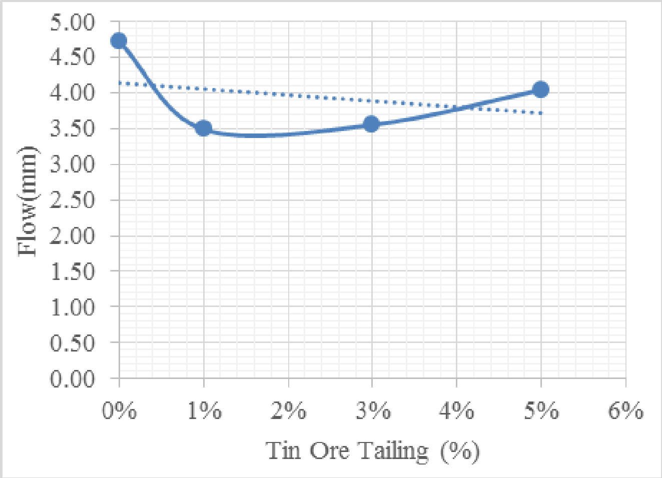

Figure 5. Flow against percentage of TOT

3.4. Stability

The stability increases with the percentage of TOT in samples (Figure 6). This indicates that presence of TOT improve aggregate bond network and increase the internal friction between aggregates. The lowest stability value is 7040N from control sample while the highest stability is 12564N from 5% TOT. JKR 2008 recommended stability should be more than 8000N. The result is consistent with a study by [12-14].

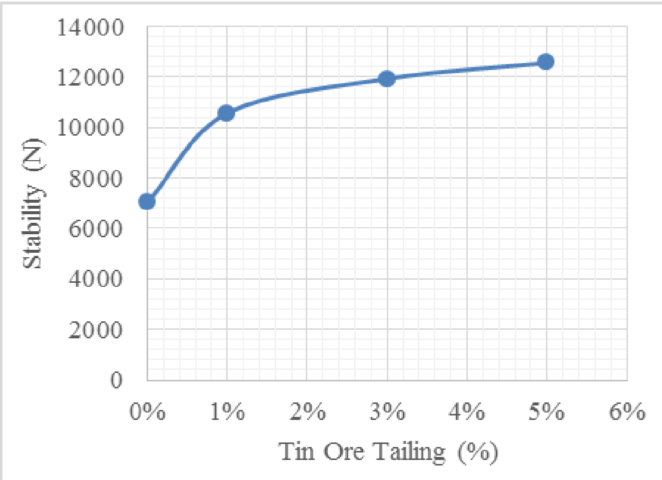

Figure 6. Stability against percent of TOT

3.5. Stiffness

The stiffness in the graph shows an upward trend in correspond to stability and flow (Figure 7). The highest stiffness came from 3% TOT followed by 5% and 1% TOT. Stiffness indicates the materials resistant to permanent deformation. Thus, a high MQ mixture shows a high tendency of stiffness and can resist creep deformation to a large extent. JKR 2008 requires stiffness to be more than 2000N/mm.

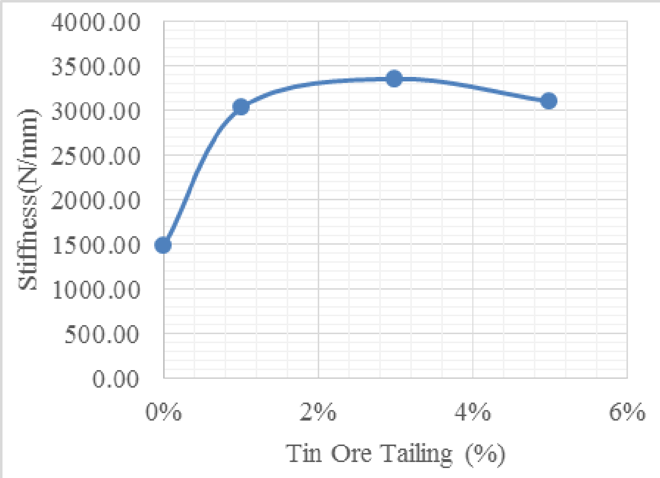

Figure 7. Stiffness against percent of TOT

3.6. Moisture susceptibility
A mix with higher tensile strength provides better resistance to fatigue and thermal cracking [3, 11]. The tensile strength of modified samples generally is higher than control sample [15]. Based on Figure 8, the highest ITS is TOT5% with 0.7MPa (dry) and 0.53MPa (wet). The TSR of the samples have not achieved the recommend TSR value of 80% by AASHTO T283 although TOT (1%) shows TSR of 82% but its tensile strength is the lowest among other samples.

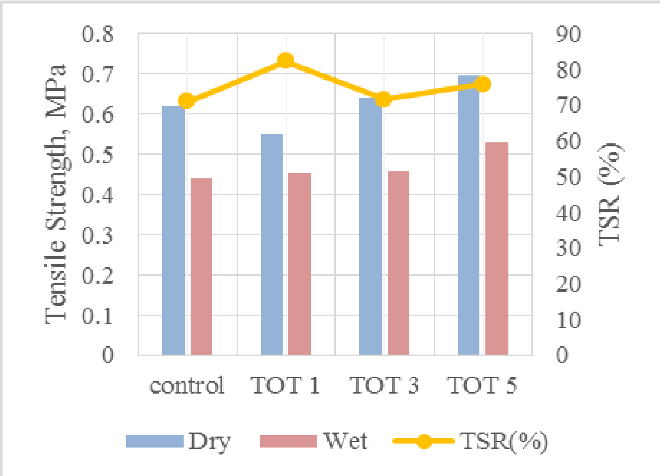

Figure 8. Tensile strength (ITS) against percent of TOT and TSR

4. Conclusion
In general, the addition of tin ore tailing in asphalt mixture shows improvement in the mixture performance. The optimum TOT percent is 5%. Although some of the results are not within JKR 2008 specifications, the study with tin ore tailing is promising prospect in pavement design. It is recommended to conduct studies with different percentage of bitumen content with TOT and possibility of replacing fine aggregate in asphalt mixture.

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