Use of Reclaimed Asphalt Pavement (RAP) in Malaysian Hot Mix Asphalt (HMA)

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ABSTRACT: Recycling technology for advanced pavement materials has been realistically proven to be more economical, energy-saving and substitute materials to traditional ones. In making the recycled premix, asphalt surfacing reclaimed from old flexible pavement are reprocessed along with some virgin materials to produce modified asphalt mixes. They may be placed on the same roadbeds from which the reclaimed asphalt pavements (RAP) came but their uses can be applied wherever the needs dictate. Recycled premixes vary widely in their contents of RAP, virgin aggregates, fresh asphalt and recycling agents that much react as additives or fibre or filler. A state of Selangor road improvement projects was selected as an initial study. The first step is to establish the probable causes of pavement distresses. Towards the end, the original pavement design and construction records are rigorously reviewed. The usual laboratory tests are carried out to test the physical and structural properties of the RAP. Moreover, the aggregates and the ageing asphalt that form the RAP have specific characteristics that definitely must be separately evaluated. RAP may range from as little as 10 percent to as much as 70 percent of the final mixtures. These asphalt paving mixtures with certain amount of RAP requires standard testing in addition to the common Marshall procedures. The considerable composition of RAP that is applicable in asphalt mix must be obtained. Such standard testing are aggregate gradation, typical aggregate and asphalt tests plus the performance analysis.

KEY WORDS: Reclaimed asphalt pavement, waste, hot mix asphalt, recycling, recycled premix.

1 INTRODUCTION

Reclaimed Asphalt Pavement (RAP) is termed as removed and/or reprocessed pavement materials containing asphalt and aggregates. In consequence, asphalt pavement is generally removed either by milling or full-depth removal technique. Milling entails removal of the pavement surface or resurfacing work using a milling machine, which can remove up to 100 mm thickness in a single pass. Full-depth removal represents the reconstruction work most likely for road rehabilitation and involves ripping and breaking the pavement using a rhino horn on a bulldozer and/or pneumatic pavement breakers. Unlike milling process, it can cause the pavement structure to be taken out until 300 mm deep.

In most instances, the broken materials is picked up and loaded into haul trucks by a front-end loader before being transported to a central facility for processing stage. At the asphalt mix plant, the RAP is processed using a series of operations including properly crushing, screening, conveying and stacking. Although bulk of old asphalt pavements is recycled at central processing plants, asphalt pavements may be pulverized in place and incorporated into granular materials or stabilized base courses using a self-propelled pulverizing machine. Hot in-place and cold in-place recycling processes have greatly evolved into continuous train operations that include partial depth removal of the pavement surface, mixing the RAP with beneficiating additives such as virgin aggregates, binder and/or softening or rejuvenating agents to improve binder properties, and placing and compacting the resultant mix in a single pass.

The National Statistics Department Report on the latest demographic data cited that Malaysia population is amounted approximately to 25.581 million as of 2004 in comparison to the great increase in the number of private vehicle registration in Malaysia up to July 2003 that is nearly 6.03 million or 48.28% is motorcycle and 5,253,891 or 42.07% reflects the quantity of motorcar. During the first seven months in 2003, the total registered vehicle in Malaysia is roughly 12.5 million. The use of motor vehicles will without a doubt continue to increase as the Highway Network Development Plan (HNDP) Study by the Highway Planning Unit (HPU), Ministry of Works with the assistance of the Japan International Cooperation Agency (JICA) had estimated that the overall mode share of road transport will constantly remain very high at 99.6% for passenger traffic and 98.5% for freight traffic within the West Malaysia under the 'Do-something' scenario in 2010. Likewise, the number of daily vehicle trips in Peninsular Malaysia was forecast to rise from some 7 million in 1991 to 17.8 million by 2010, explicitly, manifesting an average traffic growth rate of 10.9% per annum whereas the daily vehicular traffic demand is expected to grow annually by some 6.0% from 1991 to 2010 over in East Malaysia.

The growing need for better urban land transport systems, the road network length as well as a healthier environment has led to ever increasing levels of research particularly the formulation of new, economical and practical products, materials and mix design methods towards future challenges. Furthermore, most of Malaysian roads i.e., almost 90% as of Malaysian Roads General Information 2003 is paved with bitumen, thereby Asphalt Pavements need to evolve drastically as pavement demand is absolutely high. Other road statistics reported that 94.6% of Federal Roads and 73.5% of State Roads (including Municipality Roads) are paved with length of roads totalling 76,416.51 kilometres in 2003. When the number of motorised vehicles is rising greatly, there is a high demand of pavement maintenance and management at present, and the relative cost is also increasing because of unwanted pavement defects. Pavement rehabilitation works are also becoming more important as the road network approach maturity. The rehabilitation work undeniably produces tonnes of asphalt pavement wastes that have to be disposed and reused (recycled) in the right way in order to preserve the environment. Therefore, the tremendous road expansion makes the natural resources such as bituminous materials and aggregates become scarcer, insisting on the creation of new, alternative and innovative ways of using the wastes in order to reduce the overall project cost and save the surroundings.

Another aspect is advancements in pavement materials require better understanding of performance due to pavement common problems and cost factors include increasing life cycle cost and shrinking road budget by authorities and increasing road network length. For example, the expected operation and maintenance costs are RM 333 million for year 2004 whereas the respective upgrading cost is close to RM72 million. So we need better roads, longer lasting roads and less costly roads. The significance of this project is to optimise the usage of waste materials such as RAP, which is abundant, easily available and this is in line with the present and future trends that is to deplete local resources. In an effort to find an alternative but cost effective solution, RAP seems to offer an option additive for HMA research. Also, it may help reducing reliance on landfills and lessening road construction wastes in the country by reusing RAP instead of haph azardly disposing it everywhere.

1.1 Objectives

The main objective of this study was to evaluate the performance of local ingredients of RAP in HMA by analysing recycled premix's results of experimental works done with the Marshall standard criteria and then comparing these results with a control HMA sample's results. Other specific objectives were to analyse the specific properties of the selected RAP by conducting the appropriate standard laboratory tests and to determine the optimum binder content (OBC) of RAP's bitumen in the modified HMA.

2 RECLAIMED ASPHALT PAVEMENT (RAP)

How often the resurfacing work is done, the amount of patching and/or crack sealing and the likely presence of former seal coat applications will all have an influence on RAP composition. The physical properties of RAP are largely dependent on the properties of the constituent materials of the asphalt paving mix and the type of premixes that forms the layers of flexible pavement's surfacings. Its quality indeed can vary since the old asphalt pavements are obtained from various sources. The substantial differences between all asphalt mixes are from the aspect of aggregate's quality, size and consistency. From the theoretical point of view, aggregates that make up wearing course must have high resistance against skidding and abrasion (polishing), so that contribute to satisfactory friction resistance characteristic. By all means, aggregates in the underlying layers may be of lower grades, where polishing impact is not of concern.

Both milling and crushing can cause aggregates degradation. Crushing does not produce as much degradation as milling because the gradation of crushed RAP is generally not as fine as milled RAP, however finer than virgin aggregates crushed with the same type of equipment. Hence, the particle size distribution of milled or crushed RAP may vary to some extent, depending on the type of equipment used to generate the RAP, the type of aggregates in the pavement structure and whether any aggregates of the underlying base or subbase courses has been unintentionally mixed with the RAP during the premix removal. RAP is milled or crushed down to 37.5 mm (1.5 in.) or less with a maximum allowable top size of either 50.0 mm (2.0 in.) or 63.0 mm (2.5 in.). A typical range of particle size distribution as a result of milling or crushing the RAP is shown in Table 1. Studies in California, North Carolina, Utah and Virginia have resulted in mix fraction passes a 2.36 mm (No. 8) sieve before and after milling to increase a pre-milled from 41 to 69 percent and a post-milled from 52 to 72 percent respectively. The fraction passes a 0.075 mm (No. 200) sieve is expected to increase from about 6 to 10 percent to a range of 8 to 12 percent. Based on Asphalt Institute, most sources of RAP was a well-graded coarse aggregates or perhaps slightly finer and more variable than crushed natural aggregates.

Table 1: A particle size distribution of RAP (percent by weight passing)

Screen size (mesh)	Percent finer after processing or milling
37.5 mm (1.5 in.)	100
25.0 mm (1.0 in.)	95 – 100
19.0 mm (3/4 in.)	84 – 100
12.5 mm (1/2 in.)	70 – 100
9.5 mm (3/8 in.)	58 – 95
4.75 mm (No. 4)	38 – 75
2.36 mm (No. 8)	25 – 60
1.18 mm (No. 16)	17 – 40
0.60 mm (No. 30)	10 – 35a
0.30 mm (No. 50)	5 – 25b
0.15 mm (No. 100)	3 – 20c
0.075 mm (No. 200)	2 – 15d

a. Usually less than 30 percent
b. Usually less than 20 percent
c. Usually less than 15 percent
d. Usually less than 10 percent

A unit weight of milled or processed RAP depends on the type of aggregates in RAP and moisture content of stockpiled RAP. It is ranging from 1940 to 2300 kg/m^3 (120 to 140 Ib/ft), which is slightly lower than that of natural aggregates. RAP's moisture content will increase during its storage and stored crushed RAP is measured to amass moisture up to 5 percent or higher. Crushed or milled RAP can also pick up a considerable amount of water if it is exposed to rain. However, some stockpiled RAP may collect moisture as high as 7 to 8 percent during periods of extensive precipitation. Therefore, stockpiling of crushed or milled RAP should be kept to a minimum.

The asphalt cement of RAP typically ranges between 3 and 7 percent by weight and somewhat harder than new asphalt cement primarily due to exposure of the pavement surface to atmospheric oxygen (oxidation) during service and weathering. But, RAP obtained from most of wearing courses has asphalt content around 4.5 to 6.0 percent. This recovered asphalt usually exhibits low penetration and relatively high viscosity values, depending on the amount of time the original pavement has been in service. For instances, penetration value at 25^{o}C (77^{o}F) is likely to range from 10 to 80 while the absolute viscosity value at 60^{o}C (140^{o}F) may range from as low as 2,000 poises (equivalent to AC-20) up to as high as 50,000 poises or greater, subject to the extent of aging. In most cases, the viscosity ranges from 4,000 to 25,000 poises can normally be expected from this recovered asphalt.

The overall chemical composition of RAP is essentially similar to that of the naturally occurring aggregates that is its principal constituent. Basically, molecular weight aliphatic hydrocarbon compounds is a dominant component of asphalt cement apart from small concentrations of sulfur, nitrogen and polycyclic hydrocarbons (aromatic and/or naphthenic) of very low chemical reactivity. Similarly, it is a combination of asphaltenes and maltenes (resins and oils) as stated by (Thagesen, 1996). Asphaltenes is more viscous than maltenes and plays a major role in determining asphalt viscosity. Oxidation of hardened asphalt means the oils changes naturally to resins and finally forms asphaltenes.

The mechanical properties of RAP are much influenced by the type of asphalt paving mixtures, methods utilized to recover the RAP and the degree of processing necessary to prepare the RAP for a specific application. The compacted unit weight of RAP will decrease with an increasing unit weight and a maximum dry density value is estimated to be between 1600 kg/m^3 (100 Ib/ft) and 2000 kg/m^3 (125 Ib/ft). RAP that contains trap rock aggregates has California Bearing Ratio (CBR) value in the range of 20 to 25 percent. Nevertheless, the asphalt in RAP has a significant strengthening effect over time when RAP is blended with traditional aggregates for use in granular base that is asphalt mix that consists of 40 percent RAP has produced CBR above 150 after one week.

The first sustained effort to recover and reuse old asphalt paving materials was conducted in 1974 at Nevada and Texas even though some form of pavement recycling had been practised as early as 1915. Entirely bolstered by the Federal Highway Administration (FHWA), more than 40 states in the United States performed and documented RAP demonstration projects between 1976 and 1982. Now, RAP is routinely accepted as aggregates substitute and a portion of the binder in asphalt mixes in nearly 50 states. Normally, substitution rates of 10 to 50 percent or more are introduced in mixes by means of hot or cold recycling and sometimes used widely as aggregates in base or subbase construction. Other source of reference estimated that approximately 33 million metric tons (36 million tons) or 80 to 85 percent of the excess asphaltic concrete generated presently was being reused either as a portion of HMA, cold mixes or as aggregates in unbound or stabilised layers. If not, it was stockpiled and recycled eventually. Where the excess asphaltic concrete was practically less than 20 percent of the annual amount of RAP generated, or where RAP was commingled with other materials or facilities were not readily available for collecting and processing RAP, it was dumped in landfills or occasionally in the right of way. The recent advanced technology has even made it possible to be recycled at 90 to 100 percent in HMA.

3 METHODOLOGY

This preliminary research project focused on the first trial making of designated HMA that made fully use of RAP to substitute the fresh bitumen. The RAP was taken at one selected road stretch in Sungai Rasah-Padang Jawa, Selangor, which currently was maintained periodically by the Public of Works Department Malaysia (PWD) and Roadcare (M) Sdn. Bhd., applying milling process. The studied site was seriously experiencing surface defects and permanent deformation. Several tests were conducted to determine the characteristics of RAP prior to use in HMA. This was to make sure that the contents of RAP or in precise, milling wastes did not pose problems in terms of durability and stability of the mix.

To recover the coated, aged asphalt cement of the RAP, the RAP sample was thoroughly treated through a few stages of Abson Binder (Bitumen) Recovery Test that was using four different types of apparatus viz. Extraction Bottle method, Centrifuge Extractor method, Rotary Film Evaporator technique and Vacuum Distillation process. At the beginning, the milling waste was heated up in an oven at least for 45 minutes at 100^{0}C so that the binder was easily bleeding from the paving mixture. Methlene Chloride was then put into it to further loose up the bonding between aggregates and bitumen before placing it into the extraction bottle. This bottle was fixed on the roller machine. It was rotated for about 30 minutes to produce binder solution and remove the aggregates. Functioning as a filtration machine, the centrifuge extractor is meant to dissolve small particles from aggregates in the binder solution. The entire process was given in ASTM D 2172. Subsequently, methlene chloride was extracted by rotary film evaporator and the binder solution in the mould was made spinning consistently until it become very thick. The evaporated methlene chloride was gathered in another outlet of rotary film evaporator. The remaining methlene chloride was eliminated using vacuum distillation apparatus by heating binder at about 145^{0}C and carbon dioxide that served as dissolving agent was speeding up the process around five minutes.

The asphalt cement binder of RAP was checked for its physical and rheological properties using the common asphalt tests like Penetration Test, R & B Softening Point Test and Penetration Index nomograph or formula. It was made untreated or remained raw before mixing in aggregates mixture.

RAP-HMA mix contained new aggregates (granite), binder of RAP and filler. The selected aggregates was based on local aggregates gradation i.e., ACW14 as tabulated in Table 2, whilst fine aggregates passed 3.35 mm sieve but retained at 0.075 mm sieve. The filler was cement and its amount was limited to only 2% or 22.5 g from the total weight of the mixture.

Table 2: Aggregates Gradation for ACW14

Sieve Size (mm)	% Passing	% Retained	Weight (g)	Accumulated Weight (g)
20.00	100.0	0	0	0
14.00	87.5	12.5	140.6	140.6
10.00	79.0	8.5	95.6	236.2
5.00	62.0	17.0	191.3	427.5
3.35	53.5	8.5	95.6	523.1
1.18	37.5	16.0	180.0	703.1
0.425	23.5	14.0	157.5	860.6
0.150	11.5	12.0	135.0	995.6
0.075	7.0	4.5	50.6	1046.2
Pan	0	7.0	78.8	1125.0

Fifteen Marshall asphalt cakes were prepared because the binder contents were ranging from 4.5% up to 6.5%, with 0.5% increments. The compactive effort applied was 75 blows. All samples had been largely subjected to two different tests such as the Density-Voids Analysis that give information on physical properties, and the performance tests that measure the mechanical properties i.e., Marshall Stability - Flow Test. The common Marshall Test Property smooth curves were drawn separately. The optimum aged binder content (OBC) was directly obtained by averaging the percentages of bitumen content at the maximum points for graphs Unit Weight, Marshall Stability and four percent of VTM (using mean of limits) against the percentage of asphalt, respectively. The stability and flow values for this OBC can then be obtained from the appropriate graphs and thereupon to compare the final values with the recommended Marshall criteria.

4 RESULTS AND DISCUSSIONS

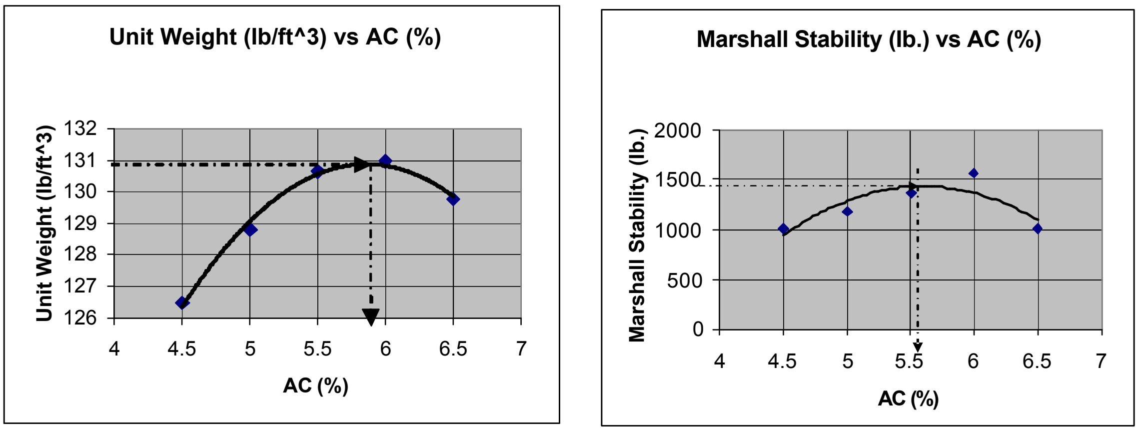
4.1 Physical Characteristics of RAP's Binder

The penetration of asphalt cement at 25^0C was 143 and the temperature at which a phase change occurred in this binder was recorded by its softening point that was $43.25\,^0$C. In other words, the binder at 43.25^0C cannot support the weight of a steel ball and straight away start flowing. This paving asphalt cement had a penetration index (PI) between +1 and -1. Therefore, binder with this PI value was suitable for use in the pavement construction and maintenance. The lower the PI of an asphalt cement, the higher its temperature susceptibility. These types of binder normally exhibit brittleness at both low and high temperatures, and are very much prone to transverse cracking in cold climates as well as fatigue cracking and reflective cracking in tropical climates.

4.2 Performance of Modified HMA

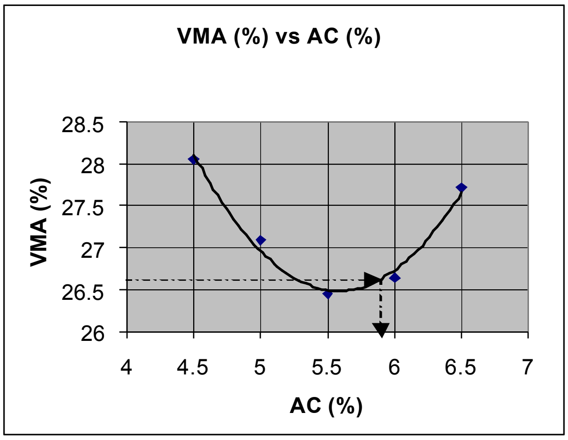
Density-Voids Analysis resulted in average bulk specific gravity of compacted mixes for all test specimens varied from as low as 2.027 to as high as 2.099 for asphalt content 4.5% and 6%, respectively, whereas the percent air voids was in a range of 4.11% - 5.15% and the corresponding percent voids in compacted mineral aggregates (VMA) were 28.05%, 27.10%, 26.45%, 26.64% and 27.72%. Since specifications for aggregates used in asphalt mixes usually require this main component to be clean, tough, durable in nature, and free of excess amounts of flat or elongated pieces, silt, debris, dust and other deleterious particles or substances, it was also checked for its cleanliness and the bulk specific gravity was 2.690. The gradation of aggregates was done a few times just to meet the requirements for ACW14. In theory, the distribution of particle sizes in the aggregate mix affected the density, strength and economy of the pavement structure.

The plot of Marshall Test Property Curves for this research project is shown in Figure 1. The binder content that was corresponding to the maximum value of unit weight and stability is chosen from each of the respective plots. So, from Figure 1(a) and Figure 1(b), the asphalt content was 5.88% and 5.60% for the peak unit weight and maximum stability, accordingly. At four percent air voids in compacted mix as shown in Figure 1(d), the respective binder content was 6.25%. Therefore, the OBC was (5.88 + 5.60 + 6.25)/3 = 5.91%. The properties of the asphalt paving mixture containing the OBC were comprised of unit weight 130.9 Ib./ft^3, stability 1400 Ib., flow 9.5 units of 0.01 in., voids in a total mix was 4.2% and voids in mineral aggregates 26.63% when back calculated estimation was done on the plots.



(a) (b)

Figure 1(a) and Figure 1(b): Marshall test curves of asphalt institute method.



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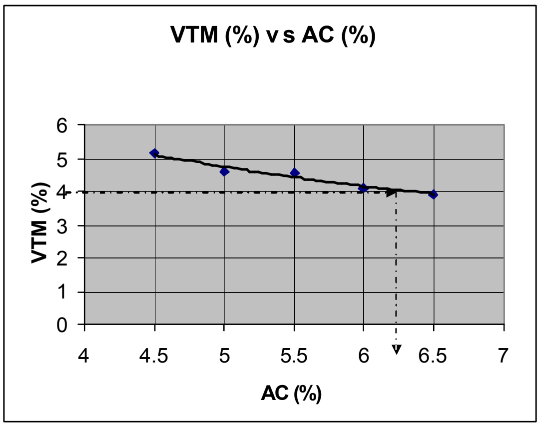

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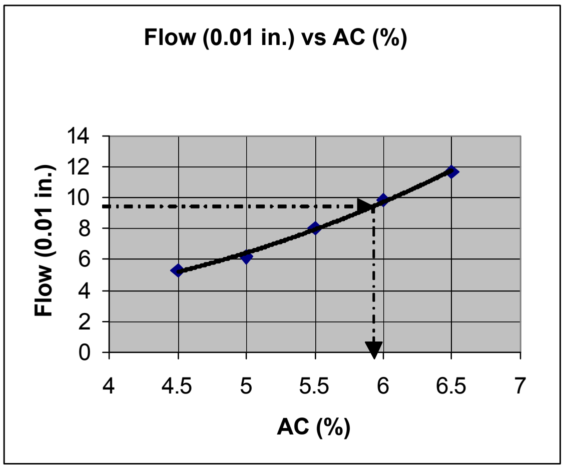

(e)

Figure 1: Plotted property curves of recycled premix.

5 CONCLUSIONS

This mixture was found meeting all the mix requirements of Marshall method for stability, flow, percent voids in total mix, and percent voids in mineral aggregates. However, the result of stability was less than the minimum limit for heavy traffic surface, thereby the trial mix can be adjusted by improving the aggregates quality. The overall results of this study proved that RAP could be recycled effectively and safely in pavement surfacings.

6 RECOMMENDATIONS

Previous RAP-related research have proven that the aggregates of RAP definitely can be reused in bituminous mixes due to almost all important properties of aggregates, for example, particle size and gradation, resistance to wear or toughness, durability or resistance to weathering, specific gravity and absorption, chemical stability, particle shape and surface texture, and cleanliness were not acutely influenced by the environmental factors, the polishing effects of traffic and the repeated traffic loadings. Therefore, it is recommended that the next study will attempt to simply recycle 100% local RAP in preparing HMA so that help creating better and more cost-effective highway and pavement construction materials and safe discarding waste materials. Furthermore, the RAP is now abundantly available at the roadside where the road maintenance works are done on a regular basis. At least, RAP offers an alternative for traditional materials in Malaysian future road industries.

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