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Experimental study to analyze the effectiveness of reclaimed asphalt pavement aggregates in asphalt mix design

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Abstract. The addition of reclaimed asphalt pavement aggregates (RAP) to hot-mix asphalt is a fast-growing potential solution towards the reduction of unfavorable environmental and economic effects of using virgin aggregates during pavement construction. Particularly within the United Arab Emirates, the process of using RAP in new pavement construction is still quite unpopular due to strict limitations and resulting performance concerns. This investigative study utilized RAP material that was obtained from a pavement site located in the city of Abu Dhabi. Following UAE specification guidelines, a 15% RAP inclusive blend was created to effectively explore how the presence of RAP can influence the HMA mix, by comparing the blend to a baseline mixture, which consisted of all natural aggregates with no RAP percentage. The tests that were performed on both samples were inclusive of maximum density, Marshall stability and flow, percentage voids in mineral aggregates, and percentage of voids filled with asphalt. The resultant data clearly indicated that RAP presence does not in any way cause a decline in the HMA mix properties in terms of Marshall properties. Nevertheless, it is still critical to carry out an analysis of the effects that a further increase in RAP percentage will have on an HMA mix, and to also carry out an investigative study regarding the economic benefits of utilizing RAP aggregates in pavement construction.

1 Introduction

Most existing road construction practices primarily depend upon natural aggregates, that are mainly extracted from quarries [1]. These extraction processes cause resultant forest loss and pollution which leads to environmental degradation. To effectually protect and stop the rapid depletion of these natural resources, it is critical to ensure adequate reserves that are capable of handling present and future aggregate demand [2]. With more than 90% of the roads in Europe utilizing hot-mix asphalt as a road construction material, asphalt concrete is a much commonly used surface for driving when compared to Portland cement concrete [3]. Furthermore, recycling of asphalt material is also carried out in much heavier amounts. The recycling process of asphalt concrete mainly includes removing and processing the existing road surface and combining it with virgin aggregates for the production of a final mix design. However, there are numerous aspects that can influence the usage of RAP in pavement construction, such as environmental and economic factors. Utilizing reclaimed asphalt pavement (RAP) aggregates can be a reasonable alternative to the use of virgin aggregates as it directly reduces the requirement of virgin asphalt binder in hot-mix asphalt production. Using reclaimed material also contributes towards energy conservation and preservation of resources, and decreases transportation costs that would otherwise be a requirement for the extraction of natural aggregates. Also, using RAP prevents large amounts of construction debris from being dumped into landfills [4].

2 Methodology

The blends studied in this research were dense-graded HMA mixtures, with a nominal aggregate size of less than 20 mm, and PG82-22 binder, which were designed according to UAE's main road specifications for heavy flows of traffic. As the average aggregate size was less than 20 mm, the original Marshall mix design method was used for the final mix production. The RAP material was obtained from a milling operation site in Abu Dhabi, and the blends were designed to consist of 15% RAP, by total weight. After characterizing and finally preparing all the materials to be utilized, lab samples were produced for investigation of Marshall properties of the mixture inclusive of RAP and its properties were compared to the Marshall properties of a baseline virgin mix with no inclusion of RAP, to understand the influence and effectiveness of reclaimed aggregates in HMA mix design. The main Marshall properties that were investigated included Marshall density, stability and flow, percentage of voids in mineral aggregates, and percentage of voids filled with bitumen.

3 Material characterization

The asphalt blends containing RAP in the study consisted of three key components; virgin aggregates, RAP aggregates, and virgin binder.

3.1 Virgin Aggregates

The aggregates were obtained from local crusher and quarries in Ras Al Khaimah. The base and surface layer mix have a nominal maximum aggregate size of 20 mm. Table 1 illustrates the properties of virgin aggregates.

Table 1. Virgin aggregate properties

Property	**Coarse aggregate**		**Fine aggregate**
	20 mm	10 mm	5 mm
Bulk specific gravity	2.87	2.84	2.78
Saturated surface dry bulk specific gravity	2.89	2.87	2.83
Apparent specific gravity	2.93	2.92	2.92
Absorption (%)	0.6	0.9	1.6
% loss by abrasion and impact		14	
Sand equivalent value			57

3.2 RAP aggregates

As RAP mostly consists of similar components to virgin HMA-aggregate and binder, it was readily integrated into the mixture. Table 2 illustrates the properties of RAP aggregates.

Table 2. RAP aggregate properties

Test description	Aggregate single size	Specified limits	Measured value
LA Abrasion	19: (3/4”)	<25%	16%
Crushing value	19: (3/4”)	<25%	15%
Flakiness Index	19: (3/4”)	<30%	13%
	9.5: (3/8”)	<30%	16%
Sand equivalent value	Combined aggregate	>70%	73%
	19: (3/4”)	>90%	98%
Partially crushed faces	9.5: (3/8”)	>90%	98%
Plasticity index	Combined aggregate	Non-plastic	Non-plastic
Soundness test ($MgSO_4$)	19: (3/4”)	<5%	2%
	9.5: (3/8”)	<5%	3%

3.3 Binder

The virgin binder utilized for this study was PG 82-22 that was supplied by the Shell Bitumen Plant in Jebel Ali, UAE. The properties of binder have been displayed in Table 3. Polymer Modified Bitumen Grade 82-22 was used as it meets the base requirements of hot climate and heavy traffic areas such as the UAE. The binder grade met the requirements in accordance with ASTM D6373 specification for the design of pavements.

3.4 Preparation of test specimens

The specimen preparation for this study followed the standard procedure stated for the Marshall method, with the use of standard test specimens that were 2.5 inches in height and 4 inches in diameter. To ensure adequate resulting data, four test specimens were created for each asphalt content percentage. As the concluding asphalt content was 4%, tests were processed based upon 0.5% increments of the content, with three values above, and two values under the expected design value, which resulted in six final asphalt content values. Therefore, the mix design made use of 24 specimens in total.

4 Results and discussions

The Marshall property results for the RAP inclusive blend were then compared to the Marshall properties of a baseline control mix non-inclusive of any RAP percentage to better understand RAP effectiveness in HMA mixtures.

4.1 Air void content determination

The Asphalt Institute recommends selecting bitumen content at the median of air voids limits (5-7%).

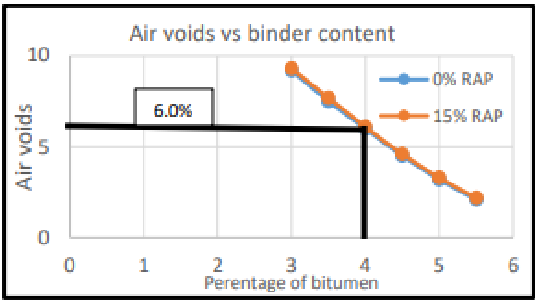

Fig. 1. Air void content against binder content

Figure 1 above demonstrated that by selection of 4% asphalt content, the air void content is measured at 6% for both the mixtures, which is considered optimal in accordance to specified limits. Hence, 4% bitumen is the optimum binder content (OBC) to be used for analysis of all further Marshall properties.

4.2 Comparison of Marshall densities

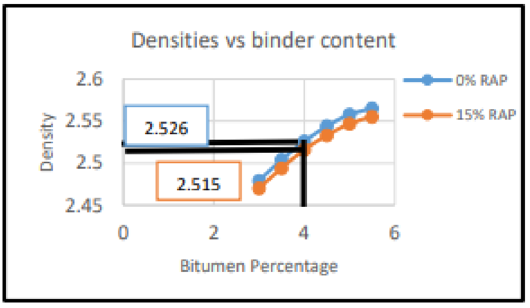

Fig. 2. Marshall density against binder content

The graph in figure 2 demonstrated only a marginal variation between the Marshall densities of the virgin and RAP inclusive blends, with the virgin mix calculating to be 2.526 and RAP mix at 2.515. As bitumen has a tendency to oxidize over time, it may become stiff and can be harder to compact which can result in a slightly low density in comparison to that of all natural aggregates. RAP presence in the asphalt mixture causes a reduction in the amount of moisture that is required to achieve the specified compaction level due to surface coating of stone particles. However, the plot is clearly indicative that a 15% RAP addition does not cause any major fluctuations to the density of the mixture.

4.3 Comparison of Marshall stability

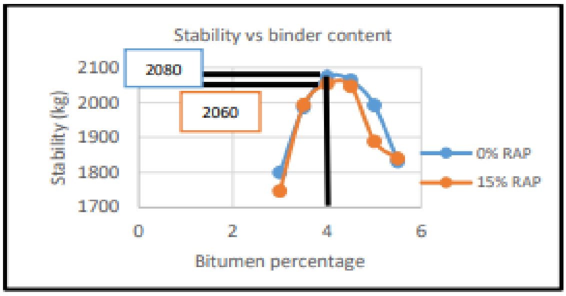

Fig. 3. Marshall stability against binder content

As seen in figure 3, both curves followed a closely similar trend, showing the stability to initially increase with an increase in bitumen percentage up to a theoretical point. This phenomenon happens because of the rise in bitumen content which provides a better aggregate bond to gain strength. However, with an even further increase in bitumen content, after approximately 4.5%, the applied load is transmitted and the aggregates are immobilized due to the hydrostatic pressure. This effect causes a decline in strength against plastic deformation, and therefore the stability decreases steeply.

By incorporating RAP aggregates, owing to the ageing asphalt, the asphalt stiffness usually increases. However, the aggregates sources in this investigation were extracted from a site that was relatively not very old, causing it to be less oxidized and stiff, which in turn led to similar stability curves in both cases. It can also be observed that stability values at the optimum binder content (4%) were also almost similar, with the virgin mix and RAP mix measuring at 2080 and 2060 kilograms respectively. Therefore, it is feasible to encourage using RAP as it is seen to not create an adverse impact on the blends' strength properties.

4.4 Comparison of Marshall flows

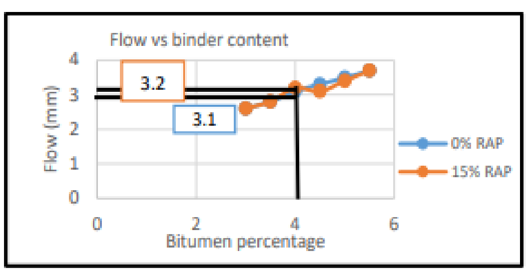

Fig. 4. Marshall flow against binder content

The flow plot in figure 4 is a representation of the behaviour of actual mixture when implemented with respect to plastic flow. With all natural aggregates, the graph showed a slow consistent increase with increased bitumen percentage. However, the acquired results for the 15% RAP addition were not linear. For instance, for OBC at 4%, the flow achieved its highest value, but noticeably decreased at 4.5% bitumen, and saw an increase later again. The fluctuation can however be considered statistically insignificant as for any bitumen content, the flow values fall with the specified range, which is 2-4 mm (ASTM D6927). At OBC, the flow value for the RAP inclusive mix can be noticed to be a little higher than that

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of the baseline mixture. A higher flow value usually indicates higher flexibility which increases the HMA pavement's ability to undergo deformation without risk of cracking.

4.5 Comparison of voids in mineral aggregates

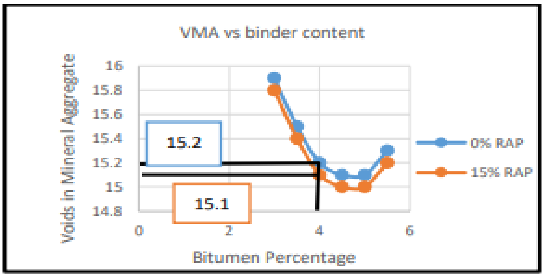

Fig. 5. VMA percentage against binder content

The graph in figure 5 demonstrated that with an increased bitumen percentage, VMA decreased consistently, then remained constant, and finally showed an increase. The initial decrease is because of the re-orientation of bitumen aggregates. Conversely, at a higher bitumen content, a thick bitumen film repels the aggregates causing a theoretical increase in VMA values. The plot reflects that at any bitumen percentage, VMA is slightly lower for the RAP inclusive blend. For OBC, the graph indicated a slightly increased VMA for the baseline mix, measuring at 15.2, compared to the RAP inclusive mix that measures at 15.1.

VMA is a critical factor within a volumetric design procedure. If too low, it can cause poor durability, and high values can result in poor stability and reduced cost efficiency due to an increased asphalt percentage. There is a requirement of minimum VMA to accomplish a feasible mix design. However, it is not desirable for the OBC to be along the VMA curve's wet side (the portion of curve reflecting an increasing VMA after a minimum value). The curve in figure 5 shows that the OBC fell within the decreasing side of the VMA curve, which is optimum.

4.6 Comparison of voids filled with bitumen

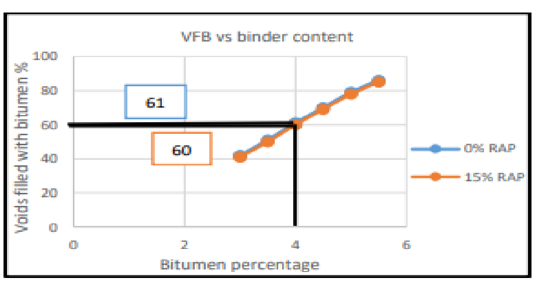

Fig. 6. VFB percentage against binder content

The graph in figure 6 for VFB values was also indicative of a similar result for both blends. At OBC (4%), the baseline blend measured at 61%, and the RAP inclusive blend followed just behind at 60%. The specified range for VFB percentage is 50-65%, in accordance with the standard construction specifications for traffic level in the UAE [9]. Usually, low traffic levels require a higher VFB range so that the durability of HMA can be increased. However, with high traffic levels, such as in the UAE, a low VFB is a key requirement since the durability and strength of the mixtures are critical.

The VFB values ensure adequate thickness of asphalt film in the mixture. At 3% and 3.5% bitumen, the VFB content was too low, measuring at about 40-50%. A low VFB value leads to poor mixture durability. However, it was noticed that after 4.5% bitumen, the VFB values shot out of the specified range and reached up to 80%. A high VFB is indicative of an unstable mix and can cause bleeding by yielding a tender mix. However, this study analysis required to ensure that all parameters complied with the OBC, which was 4%. The VFB values for the OBC remained within the specified range, and hence utilizing an OBC of 4% was adequate according to mixture design values.

5 Conclusions

- After analyzing all resultant plots for Marshall properties, unarguably the RAP inclusive mix was providing the same, if not better, quality of mixture in comparison to the baseline mix with all natural aggregates.
- All the resultant parameters remained within the optimal specified ranges for the chosen optimum binder content, which was 4%. Therefore, the long-emphasized need for the use and reuse of RAP materials from deteriorated roads can be acknowledged, as these materials still deliver desirable properties to be utilized for the surface layering of asphalt pavement roads.

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