Evaluation of Asphalt Concrete Performance Using the Hot In-Place Asphalt Recycling Method: The Case Study of Road Segments in Al-Ain, Abu Dhabi, United Arab Emirates

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ABSTRACT

materials, such as Reclaimed Asphalt Pavement (RAP), are utilized as components in asphalt mixtures. The RAP material employed in this study was obtained from the peeling of an old pavement on Zayed Bin Sultan Road from Al Bawadi Mall to Military Roundabout Al Ain, Abu Dhabi, United Arab Emirates (UAE). After its removal, RAP underwent the Hot In-Place Recycling (HIR) method. The findings were then compared with those of the conventional method. This study used 12% RAP in the Recycled Asphaltic Concrete-Wearing Course (RAC-WC) mixture. A total of 3 AC-WC mixtures were tested, with bitumen content percentages of 3.7%, 3.9%, and 4.1%. The Marshall Stability test results showed that the stability values followed a pattern involving four separate phases: Initial load adjustment, linear elastic deformation, nonlinear inelastic deformation, and post-peak stress region. The highest Marshall Stability value, 16550 N, was achieved for the mix with 3.9% bitumen content. The stability and elasticity values using HIR were higher than those obtained by deploying the conventional method.

Keywords-HIR; stability; flow; elasticity; AC-WC

I. INTRODUCTION

In flexible pavements, aggregate utilization reaches 90-95% by weight percentage and 75-85% by volume percentage [1]. To reduce the use of natural aggregates it is necessary to find alternative materials of the same quality [2-4]. Technology development in the recycled material field has encouraged the use of recycled materials as components in asphalt mixtures. One such material is the RAP [4, 5]. Authors in [5] investigated RAP employment in AC-WC mixtures (e.g. 30% addition of RAP in the mix) in order to increase the elasticity value of resistance to cracking. HIR is a pavement preservation and corrective maintenance approach that can be utilized throughout the entire width of a pavement [6, 7]. Authors in [8] presented a recycling method to heat existing pavements for a second time, conduct pulverization, spray renewing ingredients, and level pavements to their initial status. HIR seeks to restore the damaged surface of a pavement to its previous state. It can be utilized on pavements with minor fractures measuring 25-50 mm in depth [9]. Authors in [10] studied the use of RAP in hot asphalt mixtures. It was shown that the stability value increased as the RAP content in the mix increased. The highest stability value recorded at a 75% RAP mixture was 15.11 kN.

The Marshall method is used to determine the characteristics of hot asphalt mixtures [11]. The correlation between stability and flow results when utilizing the former is very important in asphalt concrete mixture design, especially in AC-WC layers. The ratio between stability and flow, known as Marshall Quotient (MQ), is used to evaluate the stiffness of the mix as well as its resistance to deformation [12]. In HIR, recycled material properties, such as asphalt content, aggregates, and additives, affect stability and flow results. Authors in [13] demonstrated that these parameters can be used to optimize asphalt mix design in order to achieve a balance between structural strength and flexibility.

The permanent deformation characteristics of asphalt mixtures can be studied using compacted cylindrical specimens regardless of the design asphalt mixture method and aggregate type. The present study aims to analyze the correlation between stability and flow (calculated through the Marshall method) in AC-WC mixtures employing the HIR method. This analysis is important to ensure that the asphalt mixture meets the required technical specifications, such as structural strength, flexibility, and durability, against traffic and environmental conditions.

II. METHODOLOGY

The utilized RAP material was obtained from an old pavement on Zayed Bin Sultan Road from Al Bawadi Mall to Military Roundabout Al Ain, in Abu Dhabi, UAE. HIR was carried out at the same location, as shown in Figure 1 while fresh materials were used in the form of crushed stones and stone ash from Al-Jaber Crusher Kadra.

Fig. 1. HIR on Zayed Bin Sultan Road, Al Ain, Abu Dhabi, UAE.

The asphalt used had 60/70 penetration grade bitumen (Bahrain Petroleum Company). The flow chart of the followed procedure is depicted in Figure 2.

Regarding HIR, the test specimens were obtained by core drilling the newly compacted pavement. The goal was to contain the optimum bitumen content.

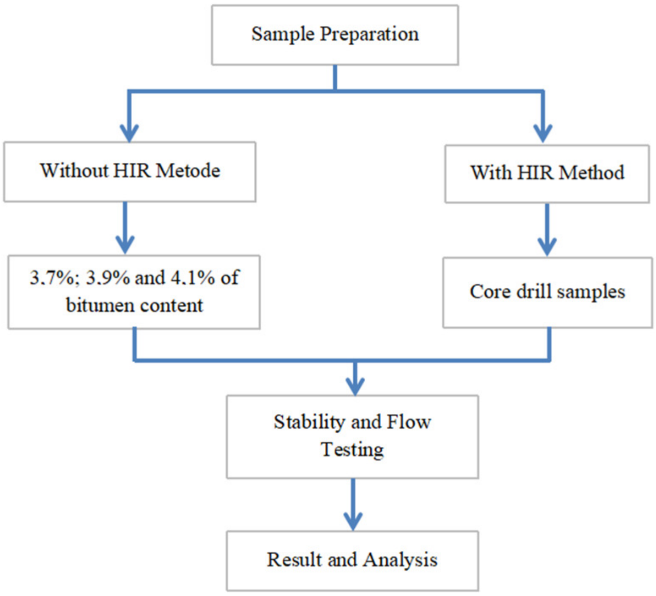

Fig. 2. Research flow chart.

The design of hot mix asphalt containing RAP utilizing AC-WC gradation follows the properties specified in [14]. Mixture gradation is presented in Figure 3.

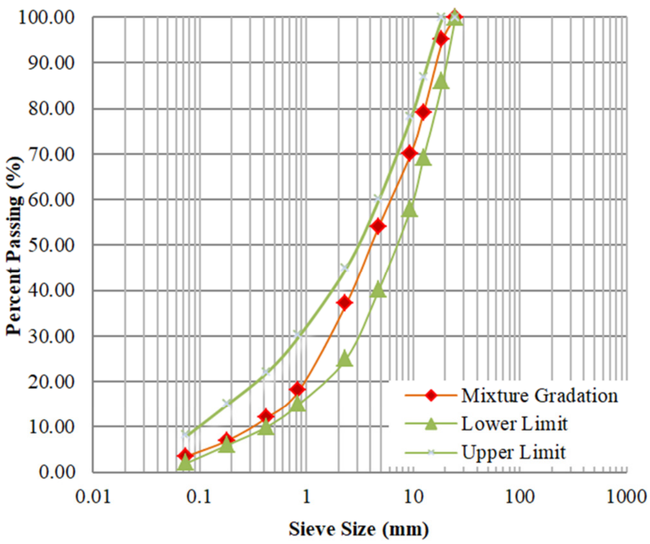

Fig. 3. Mixture gradation.

The test specimens were made in the form of cylinders with a diameter of 4 inches. The ones obtained from the core drill process, were stored for 24 hours at room temperature and then soaked in water for another 24 hours. Afterwards, they were soaked again in water for another 30 min at 60º C. Finally, the specimens were tested using a Universal Testing Machine (UTM) to determine the relationship between Marshall Stability and flow at each bitumen content.

III. RESULTS AND DISCUSSION

A. Correlation of Marshall Stability and Flow

Marshall tests were conducted on Recycled Asphaltic Concrete-Wearing Course (RAC-WC) mixtures with 3 bitumen content percentages, namely 3.7%, 3.9%, and 4.1%.

Figure 4 displays the stability and flow relationship for all asphalt mixtures. The test results revealed a consistent pattern for both methods. The highest stability value was 17750 N for the RAC-WC mix with HIR, achieved at a flow value of 10.5 (0.25 mm). This indicates that HIR is more effective in producing mixtures with higher stability than a conventional method. This is possibly due to the RAP material's condition, since it is used directly. The material is still hot after peeling and the old bitumen, which is trapped in the aggregate's grain cavities, is, therefore, softened.

In addition, when this asphalt mixture is mixed with new bitumen, the RAP bitumen can mix with the new ones to produce a homogeneous and more stable result because the homogeneous bitumen can function as an adhesive and envelop the aggregate in a better way. A further analysis of the relationship between stability and flow revealed 4 distinct phases in understanding mix behavior.

Table I shows the stability and flow values of RAC-WC mixtures both with HIR and without HIR in all 4 phases. As presented in Table I, the RAC-WC HIR mixture provided the highest stability value of 1643.21 N in the 1st phase. In the 4th phase, this value decreased to 1601.21 N. This indicates that the RAC-WC HIR mixture is able to withstand deformation due to traffic loads, thus ensuring that the road surface can withstand the pressure and the friction generated by vehicles, which may cause cracks or grooves. This high stability value can be attributed to good aggregate interlocking, increased bitumen cohesion, and high mix density, all of which are accomplished using HIR. This is due to the fact that HIR utilizes recycled materials immediately after the pavement layer removal process. As observed in Table I, the mixtures without HIR have lower stability values than those with HIR in all phases, while the flow values in all mixtures are similar, especially in the 3rd phase.

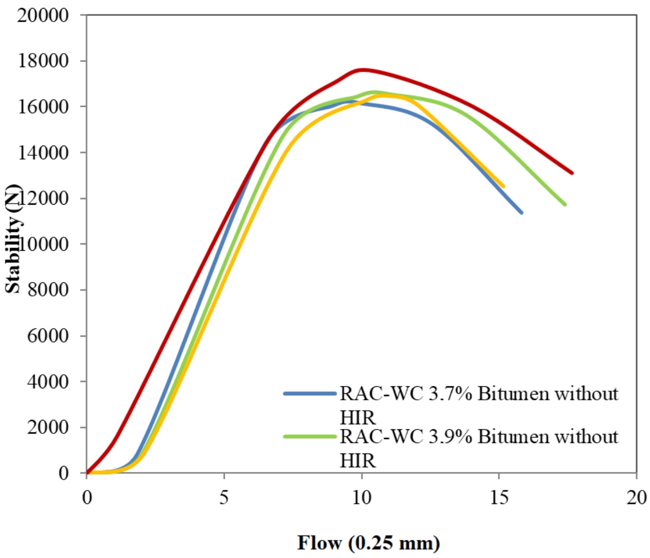

Fig. 4. Stability and flow correlation of RAC-WC mixtures.

TABLE I. STABILITY AND FLOW VALUES OF RAC-WC MIXTURES

RAC-WC	Bitumen content	Phase 1		Phase 2		Phase 3		Phase 4	
		Stability	Flow	Stability	Flow	Stability	Flow	Stability	Flow
	(%)	N	0.25 mm	N	0.25 mm	N	0.25 mm	N	0.25 mm
Without HIR	3.7	822.83	1.83	14375.27	6.49	16150.00	10.00	15236.82	12.57
	3.9	843.21	2.02	14731.32	7.14	16550.00	11.00	15614.21	13.83
	4.1	883.52	2.09	14070.39	7.27	16480.00	11.00	16069.79	12.05
With HIR	3.9	1643.21	1.12	14631.32	6.64	17550.00	10.50	16014.21	14.03

Figure 5 demonstrates that each mix shows a comparable trend regarding the stability and flow relationship. A pattern of 4 phases also emerges:

- The 1st phase occurs during the load-adjustment stage, where each bitumen content exhibits an upward curving line while adapting the load.
- The distance to the peak stress is represented by a straight line in the 2nd phase, also known as the elastic deformation phase. The complete elastic phase includes both the 1st and 2nd phase.
- In the 3rd phase, the curve reaches its peak. Due to the irreversible nature of the deformation in this phase, the mixture undergoes permanent internal changes in terms of structure.
- After reaching the peak stress, the curve exhibits a decrease in the last (4^{th}) phase. The stress-strain curve displays significant non-linear behavior in the post-peak region, indicating softening and degradation of the material or even failure of the mixture to accept the load.

Authors in [15] demonstrated the common stress-strain relationship pattern of asphalt concrete consisting of elastic and non-elastic phases. In Figure 5, it is observed that the RAC-WC with HIR curve exhibits greater sloping in the 2nd phase, indicating that RAC-WC with HIR has a longer elastic phase than the other mixtures. A more sloping curve in the elastic phase indicates that the material requires a larger increase in load to produce the same level of deformation, compared to a material with a steeper curve.

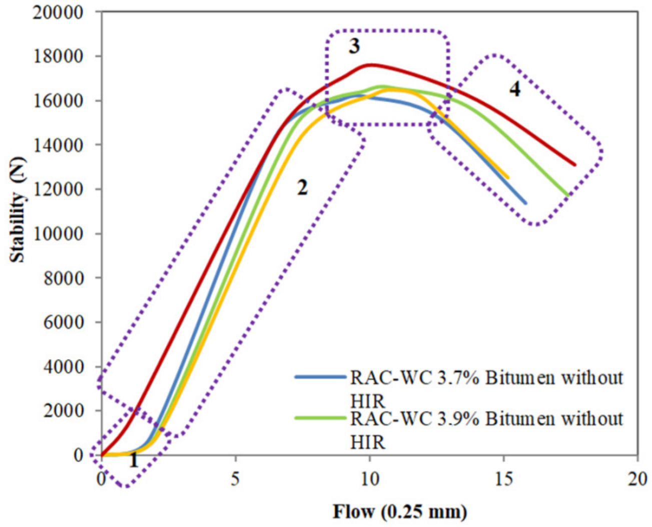

Fig. 5. Phase correlation of stability and flow of RAC-WC mixtures.

A longer elastic phase suggests that the asphalt mix has a higher capability to return to its original form after being subjected to loading. This is crucial for roads exposed to dynamic and repeated traffic loads. It also proves that the RAC-WC mix with HIR, deforms less each time an increase in load is applied, thus indicating better elastic properties.

This result reveals that RAC-WC with HIR is more resistant to load without deformation than the other mixtures. More resistant to load deformation mixtures tend to have a longer service life because they reduce the risk of structural damage due to accumulated plastic deformation.

B. Correlation of Maximum Stabillity and Elasticity

Figure 6 presents the relationship between maximum stability and elasticity values for RAC-WC mixtures without HIR and RAC-WC with HIR. The highest stability and elasticity values (17550 N and 1671.42 N, respectively) were achieved in the mixture with HIR. This indicates that the HIR mixture exhibits the highest resistance to load compared to the other mixes. Similarly, the high elasticity value indicates that this mixture has a higher stiffness level than the other three mixes. This is in line with the results of the analysis between flow and stability values, where the mixture with HIR provided the highest stability value under almost the same flow conditions.

In Figure 6, it is also exhibited that the elasticity values of RAC-WC mixtures without HIR with 3.9% and 4.1% bitumen, tend to be lower than those with 3.7% bitumen. This is because an increase in the bitumen content increases the flow value, thus resulting in a decrease in the elasticity value.

This is in accordance with the results of [4, 5], where it was demonstrated that mixtures with RAP, provided higher elasticity and stability values than mixtures without RAP. The stability and elasticity values of RAC-WC mixtures with and without HIR, meet the minimum required specifications of the Standard Construction Specification Department of Municipalities and Transport Abu Dhabi, UAE (2020), that is, at least 11760 N for stability and 1225 N for elasticity.

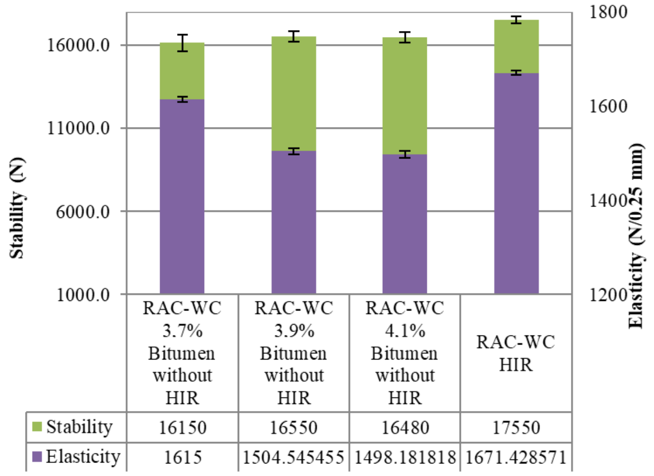

Fig. 6. Maximum stability and elasticity relationship of RAC-WC mixtures.

IV. CONCLUSION

The analysis of mechanical performance and structural behavior under simulated traffic loads revealed that the Recycled Asphaltic Concrete-Wearing Course (RAC-WC) utilizing the Hot In-Place Recycling (HIR) method, demonstrated significantly improved performance compared to the RAC-WC mixtures produced without using HIR.

The HIR method involves heating the existing asphalt pavement, softening it, and then remixing it with rejuvenating agents and new asphalt materials directly on-site, contributing to an enhanced bonding between the aged and new materials. HIR also improves mix homogeneity and the overall durability of the asphalt layer, as shown by the maximum stability value of 17550 N and elasticity value of 1671.42 N.

The superior performance of RAC-WC with HIR is also evident from the stability and flow relationship curves. The graphical analysis reveals that the RAC-WC with HIR exhibited a more gradual slope and an extended elastic phase compared to the conventional mixture. This behavior implies that the material maintains its structural integrity over a wider range of deformation stages before entering the plastic or permanent deformation zone. In other words, RAC-WC with HIR can absorb and recover from greater stress or strain without undergoing irreversible damage.

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