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Impact of Engine Oil as a Rejuvenator on the Properties of RAP Containing Asphalt Mixtures

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Abstract. In order to build roads in more sustainable and environmentally friendly ways, reclaimed asphalt pavement (RAP) must be used in large quantities. Using RAP, new asphalt can be produced with a small amount of raw materials, thus reducing the energy required to extract and refine new materials and the waste generated from demolishing old asphalt pavements. The high stiffness of RAP mixtures can make it difficult to use RAP in amounts greater than 30%. Several methods can be used to overcome this difficulty, one of which is the addition of rejuvenating agents. Therefore, this study investigated the possibility of using pure engine oil (PEO), studied its effect as a regenerating agent for RAP, and determined the optimal percentage of PEO. Three percentages of RAP were used to demonstrate the viability of using high percentages of RAP in the asphalt mixture: 25%, 50%, and 75%. In addition, four PEO percentages were tested, namely 2, 4, 6, and 8%, to determine the ideal amount that helps the RAP regain its properties. The research revealed that RAP is appropriate for hot asphalt mixtures, producing results that outperformed the virgin mixture. Furthermore, the optimal PEO percentage ranged between 4% and 6%. This study concluded that employing RAP in significant quantities in addition to PEO while sustainably building roads is feasible.

Keywords: RAP; IRS; Indirect Tensile Test; HMA

1. Introduction

Reclaimed asphalt pavement (RAP) is the reuse of aged asphalt roadways, as it is a suitable replacement for natural aggregate and binder. Utilizing RAP could decrease energy consumption, mineral consumption, pollution, and costs [1, 2, 3, 4, 5, 6, 7, and 8]. One of the advantages of using RAP is that the production cost is reduced to about 70%, and the gas emission rate is reduced to about 35% [8,9,10]. Nonetheless, the application of RAP remains limited in several nations due to the need for greater awareness and non-standard recycling requirements [10,11,12]. Therefore, it is necessary to establish a RAP assessment framework, particularly when different RAP proportions are used in the design of hot mix asphalt (HMA). Using unaltered RAP may cause the mix to become excessively stiff and difficult to compress, resulting in early pavement breakdown [13]. Increased stiffness is caused by progressive oxidation, which changes the components of asphalt and erodes its viscoelastic qualities [14]. As a result, to employ RAP in road building, the oxidized asphalt's lost characteristics must be restored using a viable re-rejuvenation procedure. Many approaches are available to address the stiffness of RAP, including using softer asphalt, a bigger volume of asphalt, and warm mix technology [15]. These approaches effectively avoid stiffness by softening the old asphalt without changing its chemical qualities.

However, softening techniques only apply to a limited number of RAP contents and are ineffective for larger ones. However, to sustainably meet the increasing demand for road construction materials, we must use more RAP without jeopardizing road performance. Rejuvenating agents have grown in popularity and have proven to be a viable option for increasing RAP content [16]. In contrast to softening methods, the rejuvenating ingredient improves the chemical structure of old asphalt by restoring lost aromatic elements and lowering the binder's overall viscosity. For higher percentages of RAP, especially more than 30%, different types of commercial rejuvenators (CRs) have been recommended [17].

However, one of the drawbacks of using CR is its infrequent availability, which, combined with the fluctuating availability of asphalt, can affect the cost of CR. This problem may be solved by using various waste products as recycling agents. Furthermore, recycling RAP with waste products could result in long-term, environmentally friendly pavement rehabilitation and recycling program. Because of their capacity to revitalize the qualities of an old binder [18,19–20], rejuvenators have garnered increased attention in asphalt technologies, possibly reducing thermal fractures and brittleness [21]. Furthermore, rejuvenators may improve the durability of asphalt mixes [22]. Waste engine oil (WEO) is a popular rejuvenator that repairs and softens old binders [23-26] and improves the workability of RAP mixtures [24,27].

Although WEO can reduce OBC [28], it has a lower percentage of volatile components because it is processed at high temperatures (above 220°C) [9], which contribute to binder hardening. The optimum rejuvenator dose is crucial [8, 29-31] because excessive rejuvenator incorporation affects stripping, adhesion, rutting, and heat cracking. Inadequate doses, on the other hand, might stiffen the mix [32-34]. Given this, various studies have calculated the effective dose of WEO to be 15% [35-37]. Based on research conducted over the past decade, it can be concluded that WEO enhances many properties, including workability [38], fatigue resistance [39], and low-temperature cracking [40]. However, the previous research focused on renewing RAP by WEO. It did not address its renewal with pure engine oil or the difference in effect between WEO and PEO. Through this research, the effect and effectiveness of PEO as a rejuvenating agent for RAP were studied. The effectiveness of using PEO to regenerate the RAP was assessed through the Index of

Retained Strength Test, the Aging Test, and the Indirect Tensile Strength. The objectives of the current study are:

a) Research and evaluation of the mechanical properties of asphalt mixtures that combine (RAP) and (PEO).
b) Examining the impact and amount of recycling agent on the (HMA)-containing material (RAP).

2. MATERIALS

This study makes use of locally accessible materials that are utilized in the building of roadways in Iraq. This work utilizes the following materials:

2.1 Asphalt Cement

The virgin asphalt (VA) binder utilized originated from the AL Nasiriya Refinery and had a penetration grade of 40–50. The required tests were performed according to the Iraqi SCRB specifications [41]. The tests showed that it conforms to the Iraqi specifications for roads and bridges. Table 1 shows the physical properties of the virgin asphalt (VA) used in the study.

Table 1: Asphalt cement properties.

Property	Result of test	ASTM specification	Iraqi Specification for roads and bridges
Penetration mm/mm at 25 ˚C	46	(ASTM and D5, 2013)	40-50
Softening point ˚C	49	(ASTM and D36, 2014)	……………..
Specific gravity at 25˚C	1.03	(ASTM and D70, 2003)	…………….
Ductility at 25˚C cm	110	(ASTM and D113, 2018)	>100
Flashpoint, °C	248	(ASTM and D92, 2009)	>232

2.2 Aggregate

The primary source of aggregates is the Al-Nabaie quarry, which produces coarse and fine aggregates. At the same time, the cement was brought from the Karbala plant and used as a mineral filler. The physical properties of the aggregates are presented in Tables 2 and 3. The middle of the Specification was taken for gradation according to standard SCRB [41]. The nominal maximum size of the aggregate is 12.5 mm, as shown in Table 4.

Table 2: Physical properties of course aggregate.

Property	ASTM specification	Value	Limit
SGB (Bulk specific gravity, gm/cm^3)	C127	2.61	…….
Water absorption, %	C127	0.53	…….
Soundness loss by sodium sulfate, %	C88	3.12	12 Max
Percent wear by Los Angeles abrasion, %	C131	20.2	30 Max

Table 3: Physicals properties of fine aggregate.

Property	ASTM specification	Value	Iraqi Specification for roads and bridges
SGB (Bulk specific gravity, gm/cm^3)	C128	2.64	………….
Water absorption (%)	C128	0.72	………….

Table 4: Gradation of aggregate for the surface layer IIIA.

Sieve No.	Sieve (mm)	Passing (%)	Limits
3/4	19	100	100
1/2	12.5	95	90-100
3/8	9.5	83	76-90
No.4	4.75	59	44-74
No.8	2.36	43	28-58
No.50	0.3	13	5-21
No.200	0.075	7	4-10

2.3 Recycled Materials

The old asphalt was brought from the highway linking the capital, Baghdad, and the city of Hila, as shown in Figure 1 after the road was damaged and had numerous potholes and cracks, where the depth of the cuts from the pavement was 5 cm. When the percentage of RAP included in the hot asphalt mix is more than or equal to 25%, the amount of bitumen present in the RAP is considered [42]. One of the essential steps in designing a recycled HMA is to determine the characteristics of the RAP. Bitumen content and sieve analysis of aggregates are mandatory requirements for RAP material characterization. Three samples were selected randomly from the stockpile of milling RAP material and submitted to an extraction test to separate bitumen from aggregate per the ASTM standard [43]. Table 5 shows the characteristics of the RAP used, and Figure 2 shows the RAP gradient.

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Figure 1: Compilation of RAP.

Table 5: The characteristics of Recycled Asphalt Pavement.

Material	Property	ASTM No.	Value
RAP Mixture Marshall properties	Stability (kN)	D-1559	31.44
	Flow (mm)	D-1559	3.44
	Bulk Density (gm/cm³).	D-2726	2.375
	Air Void (%)	D-2726	3.41
Binder Asphalt	Binder Content After Extraction (%).	D-2172	4.3

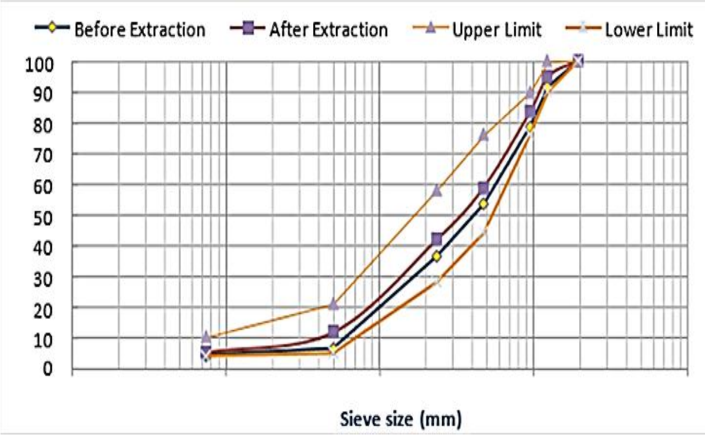

Figure 2: RAP gradation test.

2.4 The Rejuvenators (PEO)

Petroleum engine oil is a type of lubricant that is derived from crude oil through a refining process. It typically consists of base oil, a complex mixture of hydrocarbons with varying molecular weights, and various additives that enhance its performance and properties. Engine oil and asphalt are similar, as they are derived from crude oil and contain hydrocarbons. Therefore, engine oil can be used as a recycling agent. The compatibility of the rejuvenating agent with the aged binder in RAP is the most critical factor in its selection. Four different percentages of pure engine oil were employed to maintain and rejuvenate the characteristics of RAP: 2, 4, 6, and 8% of the asphalt weight, with the best amount of PEO identified for each percentage of RAP. The results showed that the optimal percentage of PEO varies according to the ratio of the RAP, as shown in Table 6. Similarly, Table 7 provides a review of the characteristics of PEO.

Table 6: Optimum ratio of PEO.

RAP Content Percentage	The Optimal Percentage of PEO
25%	4%
50%	6%
75%	4%

Table 7: Physical characteristics of PEO.

Test	Value
Specific gravity (gm/cm³)	0.89
Kinematics Viscosity at 135°C (mm/s)	3.86
Type	Petroleum
Polarity	Slight
Price per liter	$3

3. METHODS

3.1 Prepare Samples of Marshall

Marshall Samples were prepared to find the optimal percentage of asphalt content for the control mixture and the optimal percentage for the mixtures containing RAP according to the percentage of RAP. 60 Marshall samples were prepared with different percentages of asphalt content, which are as follows: 4, 4.5, 5, 5.5, and 6% of the sample weight, which is 1200 g; the results showed that the optimum ratio for the control sample is 5%, which is the same for the mixture that contains 25% RAP, while for the mixture that contains 50 and 75% RAP, the optimal ratio is 5.5%. Moreover, 36 Marshall Samples were prepared to find the optimal ratio of PEO for mixtures containing RAP after finding the optimal ratio of asphalt content. Hence, the ratios were as follows: 4% of the asphalt weight is for the mixture containing 25% and 75% RAP, and 6% is for the mixture containing 50% RAP. After finding the optimal ratios for the asphalt content and the optimal ratios for the PEO content, 48 samples were prepared to conduct the following tests: the indirect tensile test, the short-term test, the long-term test, and the Index of Retained Strength (IRS) test. The samples were prepared according to ASTM standards [14]. The sample was hammered 75 times on each face with a compactor device to obtain air voids of 4%. The specimens are shown in Figure 3.

Figure 3: Marshall samples.

3.2 Indirect Tensile Strength (ITS)

The purpose of this test method is to assess the cracking potential. One of the better test methods for determining an asphalt mixture's strength under stress is its indirect tensile strength (ITS). This test is carried out in accordance with ASTM [15] specifications to ascertain the specimen's resistance to cracking. Marshall Hammer was used to compact the specimens. Three samples were set up for testing in a dry environment at 25°C. The ITS testing procedure is shown in Table 8. The ITS test tool is displayed in Figure 4. The formula employed to derive the reported indirect tensile strength:

$$ITS = \frac{2000P}{\pi D t} \quad (1)$$

ITS=Indirect tensile strength, kPa
P = max load, N
t=specimen height immediately before test, mm
D=specimen diameter, mm.

Figure 4: The ITS test.

Table 8: ITS test condition according to the ASTM [44].

Parameters	The value used
Number of specimens	3
The load Application Rate, mm/min	50
Measuring device accuracy	0.01 N
Specimen Conditioning Before the test	Air bath for 2hr at 25ºC
Test temperature ºC	25 ± 2
compaction 75 below	each face75 below
Specimen thickness mm	63.5 ±2.5
Specimen diameters mm	101.6
Curing	24hr at Lab temperature

3.3 Index of Retained Strength Test

This test method aims to evaluate the moisture damage of asphalt mixtures. This test procedure involves determining the impact of water on compacted bituminous mixtures containing asphalt cement on their tensile strength. A numerical index of reduced tensile strength is generated by contrasting the tensile strength of newly molded and cured specimens with the tensile strength of duplicate specimens submerged in water under specific conditions. Table (9) shows the test conditions according to ASTM [45], and Figure 5 shows the sample at the ITS device. The formula gives the value of the index of retained strength:

$$IRS\,\% = (S2/S1) \times 100 \quad (2)$$

IRS %= index of retained strength
S1=ITS value of the dry specimens
S2=ITS value of the wet specimens

Table 9: Condition of the test according to ASTM [45].

Parameters		The value used
Number of specimens		6
Device		ITS Device
The load Application Rate, mm/min		50
Measuring device accuracy		0.01 N
Specimen Conditioning before the test		Water bath for 40 min at 25 ºC (wet samples) Air bath for 40 min at 25ºC (dry samples)
Compaction 75 below		each face75 below
Specimen thickness mm		63.5 ±2.5
Specimen diameters mm		101.6
Curing		24hr at Lab temperature
Specimen	3 dry without curing	Curing at water bath for 24 hr. at60 ºC
	3 curing	

Figure 5: The sample at ITS device.

3.4 Aging Test

This test consists of two terms:

- Short term: Simulation of the aging and binder absorption of HMA that takes place during the pre-compaction phase of the construction procedure.
- Long-term: The aging process that simulates the impacts of HMA aging over a pavement service life.

3.5 Preparing Mixtures

For several reasons, mixes made at an HMA plant differ from samples of HMA made in a lab in terms of their properties. One of them is that the HMA deteriorates as the mixture moves through the plant, is stored, is transported, and cools down. The air's oxygen causes the binder to change, becoming more brittle and rigid. The high temperatures encountered during construction may also drive off some volatile binder components. While the binder is still fluid enough to move into the aggregate's pores, some may also absorb into the aggregate during construction. Throughout the pavements service life, aging progresses more slowly. The aging (or oxidation) reaction moves forward more quickly in hot climates or during the hotter summer months. The conditions for these tests are shown in Tables 10 and 11 and Figures 6 and 7.

Table 10: ITS test Condition according to the ASTM [44].

Parameters	**The value used**
Number of samples	3
Device	ITS Device
The load speed (mm/mi)	50 mm/min
Accuracy of Measuring apparatus	0.01N
Samples condition before compaction	Oven at 135°C for 4 hours
Compaction 75 below	each face75below
thickness of sample(mm)	63.5± 2.5
diameter sample (mm)	101.6 mm
A treating	At the temperature of the Lab 24 hours
Sample Conditioning before the test	Air bath for 40 min at 25°C

Table 11: Condition of the test according to ASTM [44].

Parameters	**The value used**
Number of samples	3
Device	ITS Device
The load speed - mm/min	50 mm/min
Accuracy of Measuring apparatus	0.01N
compaction75 below	each face75below
thickness of sample (mm)	63.5± 2.5
diameter sample (mm)	101.6mm
A treating	At Temperature of Lab24hr
Sample Conditioning curing	Air bath for 2 days min at 85ºC
Sample Conditioning before test for	Air bath for 40 min at 25ºC

Figure 6: Sample in the oven at 135ºC for 4hr before compaction.

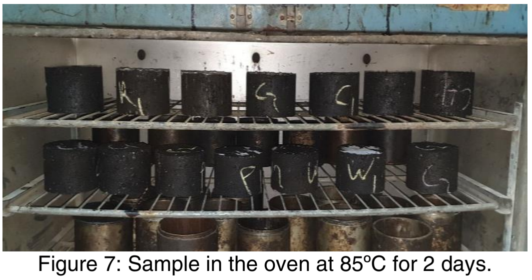

Figure 7: Sample in the oven at 85ºC for 2 days.

4. RESULTS AND DISCUSSION

4.1 Results of Marshall Test

All combinations meet the minimum stability requirements (8 kN) for high-traffic-intensity roads, air voids, and bulk density. In addition, all combinations meet the Marshall Flow criteria (2-4 mm). Figure 8 indicates that the RAP and PEO mixtures outperform the control mixture because the rap contains aged asphalt binder, which has undergone some oxidation over time. This aged binder is typically harder and more deformation-resistant than newly added asphalt binder. By adding rap to the mixture, the aged binder can contribute to the overall stiffness and strength of the asphalt, enhancing its stability. These findings were consistent with previous research (Ismael, 2018). Also, the flow increased as the amount of RAP in the mixture increased. This was because PEO worked well, and the RAP mixtures had the right amount of asphalt, which led to higher flow values. The results of the stability and flow tests are shown in Figures 8 and 9.

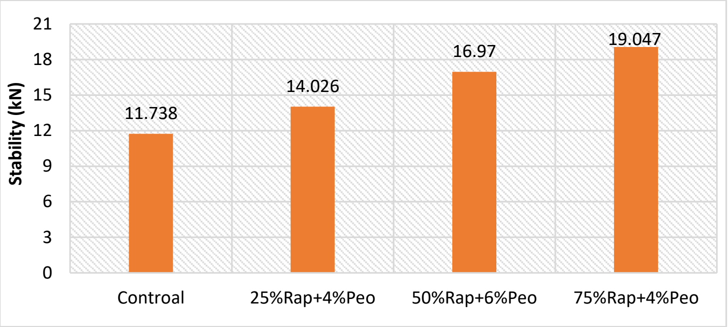

Figure 8: Values of Marshall stability.

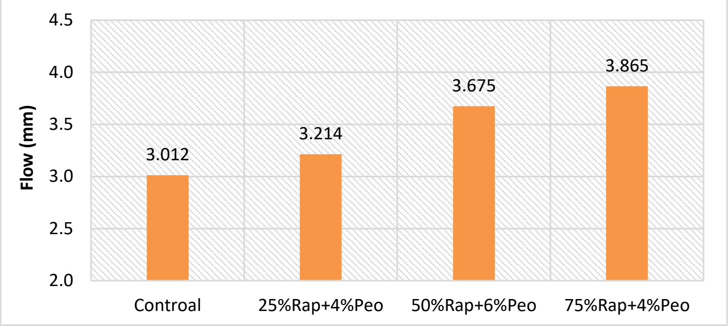

Figure 9: Values of Marshall flow.

4.2 Results of ITS Test

The indirect tensile strength test is used to assess the tensile characteristics of HMA mixes, which may be connected to the cracking properties of asphalt pavement. The results of the indirect tensile strength (ITS) test for asphalt mixes incorporating RAP are shown in Figure 10. According to the findings, increasing the quantity of RAP enhances the asphalt mixture. As seen in Figure 10, increasing the proportion of RAP raised the value of the ITS test when compared to the control mixture. This increase in ITS values may be due to RAP being added to the mix; it typically contains aged asphalt binder, which has undergone some degree of oxidation over time. This aged binder is generally harder and more deformation-resistant than newly added asphalt binder. Including RAP contributes to the overall stiffness and strength of the asphalt mix, which can enhance its resistance to cracking. Additionally, the addition of PEO can act as a rejuvenating agent. Pure engine oil softens the aged binder in RAP and improves its ability to coat the aggregates. This rejuvenation process can help restore the aging properties of the binder, making it more flexible and less prone to cracking—consequentially, the ITS value of the asphalt mix increases. For stiff mixes, greater tensile strength at failure is beneficial.

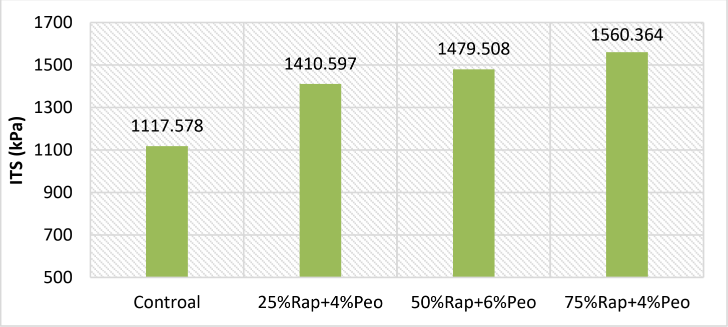

Figure 10: ITS test results at 25°C.

4.3 Results of Index of Retained Strength (IRS) Test

The IRS results showed that the recycled mixtures performed well, as increasing the ratio of RAP to pure oils increases the resistance of these mixtures to water damage. As shown in Figure 11, all results exceeded those of the control mixture, indicating they are less susceptible to moisture damage. This behavior may be explained by the stiffened binder in recycled mixes and the recycling age activity, which contributes to the mixture's improved water resistance. All (IRS) values for recycled mixes exceeded 70% and met the index of retained strength requirements of the SCRB (2004). Figure 5 depicts the results of the IRS.

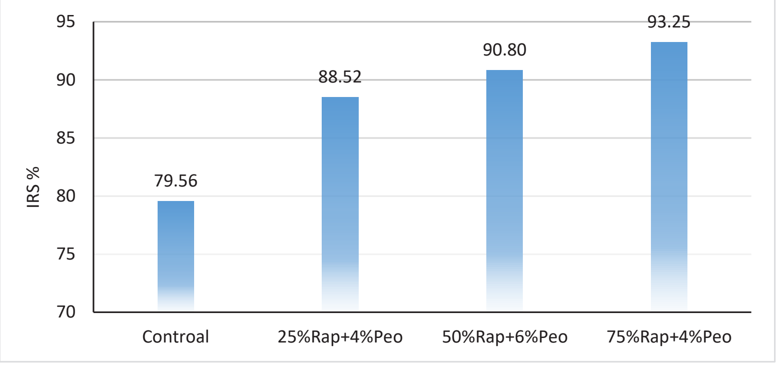

Figure 11: Water sensitivity test (IRS) check values.

4.4 Results of Aging Test

An indirect tensile strength test was performed on control, short-term aging, and long-term aging mixtures at 25°C, as demonstrated in Figure 6. Generally, it is observed that the aging process increased the ITS for the mixtures while increasing the RAP content. Figure 12 shows that short-term aging is higher than a control mix of 4.4, 2.8, 1.5, and 5.77% for mixtures that contain 0, 25, 50, and 75% RAP, respectively. Whereas it was observed that long-term aging is higher than the control mixes in about 17.5, 16.4, 24.7, and 30.3%, and short-term aging in about 12.6, 13.2, 22.9, and 23.2 for mixtures that contain 0%, 25%, 50%, and 75% RAP, respectively. This could indicate that after being exposed to aging, the mixture increased in hardness due to the stiffening of the binder by oxidation, which increased the resistance to tensile. Additionally, mixtures with a high proportion of RAP experience more aging-related effects, except for 25% RAP, which experiences the least aging-related effects.

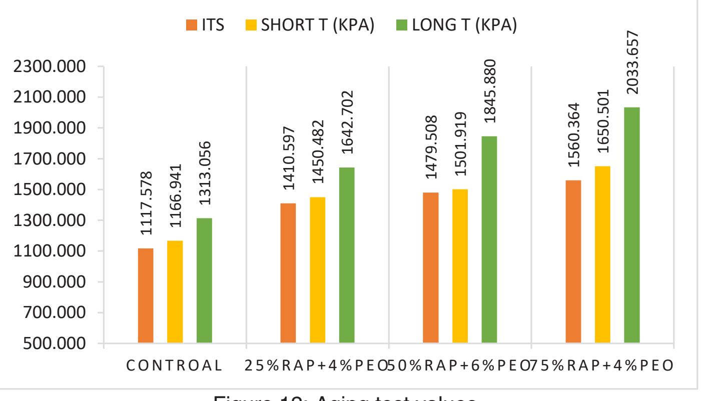

Figure 12: Aging test values.

6. CONCLUSIONS

- The study found that mixtures with high RAP content can be prepared while meeting the requirements of the hot asphalt mixture based on successful tests.
- Mixtures containing RAP and pure oil demonstrated higher stability values than virgin mixtures, with an increase in stability of 19.4, 44.5, and 62.2% for mixtures with 25, 50, and 75% RAP and pure oil, respectively.
- The flow rate also increased with the increase in RAP content, with mixtures containing 25, 50, and 75% RAP showing flow rate increases of 6.7, 22, and 28.3%, respectively, compared to the control mixture.

- The study found that including RAP increased the Indirect Tensile Strength (ITS) value, with the highest increase occurring in mixtures with 75% RAP, demonstrating a 39.6% increase compared to the control mixture.
- A water sensitivity test was performed to assess the resistance of recycled mixtures to damage caused by moisture. The findings indicated that mixtures containing RAP were less vulnerable to moisture damage and exhibited better resistance to water detrimental effects than traditional mixtures. Furthermore, the IRS test revealed that a mixture containing 75% RAP exhibited 93% resistance to moisture damage.
- Short and long aging tests revealed that the aging process significantly affected adding RAP to hot asphalt mixtures at high rates, except for mixtures with 25% RAP, which showed the least aging effect and performed better than all other mixtures.

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