

## Asphalt mixture performance and testing

### **ASSESSMENT OF RECYCLED ASPHALT CONCRETE FLEXIBILITY UNDER FLEXURAL STRESS**

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#### Abstract

Fatigue life of asphalt concrete is affected by the growth and accumulation of cracks under the action of repeated vehicular loading, aging and effect of the environment. The flexural behavior of asphalt concrete depends mainly on the flexibility of the pavement mixture which deteriorate gradually with time. Recycling could be a suitable action to reserve such properties. In this investigation, beam specimens of (400 mm) length, a width of (80 mm), and a height of (50 mm) have been prepared from reclaimed asphalt pavement RAP as well as recycled asphalt concrete with cutback and emulsion rejuvenators. Beam specimens were subjected to repeated flexural stresses in a four-point loading system under 600 load cycles at 20°C. Repeated Loading of 138 kPa was applied in the form of rectangular wave with a constant loading frequency of 60 cycles per minute and loading sequence for each cycle is 0.1 sec load duration and 0.9 sec. The vertical deflection during the test of the beam at the mid span was measured with LVDT, which was connected to data acquisition system where the deflection at various time intervals was stored and analyzed for finding strain at any number of cycles desired for every test. The resilient modulus was calculated and compared for various mixtures. It was concluded that the tensile strain for recycled mixtures decreased by (16.5 and 22.2) % for recycled mixture with cutback and emulsion respectively as compared with reclaimed mixture at 20°C. The reduction in Resilient Modulus under repeated flexural stress was (10.4 and 19.4) % for recycled mixtures with (cutback and emulsion) as compared of the aged mixture respectively. The percent of reduction in Resilient Modulus under repeated flexural stress was (10.4 and 19.4) % for recycled mixtures with (cutback and emulsion) respectively as compared to that of the aged mixture.

## 1. INTRODUCTION

The sustainability of asphalt concrete pavement can be achieved by recycling process of reclaimed flexible pavement materials. The reclaimed asphalt pavement RAP material can be obtained from milling of existing distressed pavement surfaces, (Sarsam, 2007). The recycling of pavements is considered as a sustainable option, since it is a process with environmental and economic benefits. Using RAP in the reconstruction of pavement could produce an economical and environment-friendly process, (Al-Qadi et al, 2007). Recycling is the process of reusing the existing pavement materials that no longer serve the traffic effectively. The impact of three types of recycling agents with nanomaterials on fatigue behavior of recycled asphalt concrete has been investigated by (Sarsam and AL-Shujairy, 2014). Beam specimens were constructed and subjected to fatigue resistance test under repeated loading. The evaluation of fatigue life was discussed through three selected parameters, the slope, the intercept, and the rut depth, which was measured at 5,000 cycles. It was concluded that the control mixture has higher resistance to rutting as compared with the recycled mixture while the recycled mixes exhibit higher tensile strain. The durability of RAP after recycling was investigated in terms of rutting resistance and fatigue life on beam specimens by (Sarsam and AL-Shujairy, 2015). It was concluded that the fatigue increased by (608, 66, and 265) % for recycled mixtures with (Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash) respectively as compared with aged mixture. (Zaumanis et al, 2016) investigated the concept of 100% recycling, determine whether such mixtures can perform as well as conventional asphalt mixes and if yes, develop a mixture design method for 100% recycled asphalt. Extensive rheological, micromechanical and chemical characterization tests were performed with select rejuvenators to confirm true rejuvenation of aged binders. The final proof of rejuvenation was a series of 100% RAP mix tests. The results indicated that with appropriate mix design and choice of rejuvenators, significant improvement in low temperature cracking resistance can be achieved while providing a moisture and rut resistant mixture. With the use of some rejuvenators, a long-term performance equal to that of reference virgin mix was achieved. Based on these findings a framework for designing 100% recycled asphalt mixtures was developed. (Behnood, 2019) stated that the use of high amounts of RAP can potentially cause durability-related distresses such as cracking and raveling due to the presence of severely aged bitumen binders. Rejuvenators have been widely used to overcome this issue and to mitigate the problems associated with the use of aged binders. They can improve the viscoelastic and rheological properties of asphalt mixtures containing RAP. (Bańkowski, 2018) carried out laboratory and field test to verify the suitability of bituminous mixtures with 50% content of RAP as related to fatigue life. Fatigue life was evaluated in terms of mixture durability as well as pavement structure life. The results of laboratory tests of the basic properties of binders and mixtures, as well as the results of advanced tests such as fatigue life and stiffness, were discussed. It was concluded that the addition of RAP slightly deteriorated the fatigue properties. RAP samples have been collected by (Pradyumna and Jain, 2014) and laboratory studies have been carried out to optimize the percentage of usable RAP. Recycling agent has also been used in this study and the dosage of the recycling agent has been found as 10% by the weight of the bitumen present in RAP. The comparison of properties of mixture with recycling agents, which has been prepared in laboratory, and commercially available RAP, and their performance has been compared with virgin mixes. (McDaniel et al, 2012) explored the effects of the inclusion of RAP with poor or unknown aggregate qualities in asphalt surface mixtures to establish maximum allowable RAP contents to provide adequate friction. The effects of RAP on thermal cracking were then investigated at the potential allowable RAP contents. The testing showed that the addition of poor-quality RAP materials did impact the frictional properties and cracking resistance of the mixtures, but that lower amounts of RAP had little effect. The frictional performance of the laboratory fabricated, and field-sampled RAP materials was acceptable at contents of 25% but may be questionable at 40%. (Lin et al, 2012) studied the effect of adding different ratios (from 10 to 40%) of three recycling agents to the reclaimed asphalt concrete. The study includes a variety of tests designed to determine the difference between the three recycling agents in terms of indirect tensile strength, and stability value of Marshall specimens. The results show that adding the recycling agent increased the indirect tensile strength and stability value. The aim of this investigation is to assess the flexibility of using 100% RAP after recycling with cutback and emulsion. The deformation behavior of the beam specimens under repeated flexural stresses will be monitored in terms of total, permanent and resilient microstrain. The influence of rejuvenators on resilient modulus and tensile strain will be evaluated.

## 2. MATERIALS AND METHODS

### 2.1. Reclaimed Asphalt Concrete Pavement Materials RAP

The Reclaimed Asphalt Concrete Pavement Materials RAP was obtained by the rubblization of the binder course layer of asphalt concrete of the highway section at the province of Babylon. This highway experiences heavily deterioration with various cracking modes and rutting. The Reclaimed asphalt mixture obtained was assured to be free from deleterious substances and loam that usually gathered on the top surface of the pavement. The reclaimed material was milled from the roadway section, heated, combined, and reduced to testing size as per American association of state highway and transportation officials (AASHTO, 2013); two representative samples of the RAP were subjected to ignition test according to (AASHTO T 308, 2013) procedure to obtain the overall gradation, binder and filler content, and properties of aggregate. Table 1 demonstrates the properties of RAP materials after ignition test.

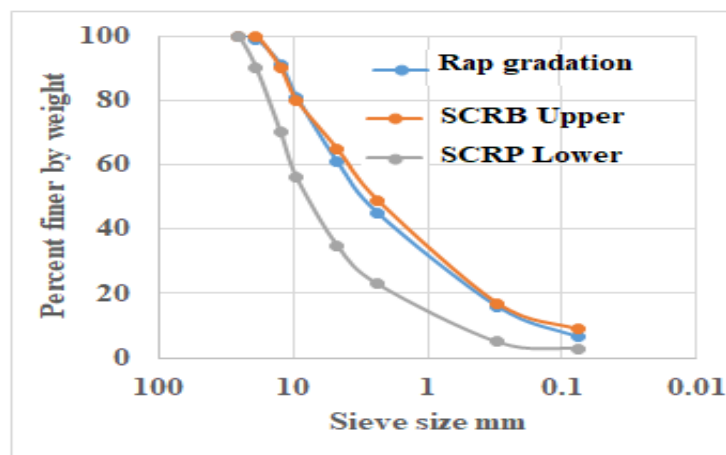
After the gradation analysis of RAP was determined; six samples have been selected randomly from the rubblization process of material stack. These samples were subjected to ignition test to isolate binder from aggregate. The aggregate was sieved and separated into various sizes to calculate gradation for each sample. The differences between samples were in a minor extent, and the average gradation of the six samples obtained is shown in Figure 1, which illustrates that the gradation of RAP aggregate for binder course layer exhibit the finer side of the specifications of roads and bridges (SCRB, 2003). Figure 2 demonstrate the reclaimed asphalt concrete pavement RAP.

**Table 1. Properties of RAP materials after ignition test.**

Material	Property		Value
Asphalt binder	Binder content, %		5.46
Coarse aggregate	Bulk specific gravity		2.59
	Apparent specific gravity		2.63
	Water absorption, %		1.071
	Wear% (Los Angeles abrasion)		23
Fine aggregate	Bulk specific gravity		2.601
	Apparent specific gravity		2.823
	Water absorption, %		1.94
Mineral filler	Percent passing sieve No. 200		98
	Specific gravity		2.85
Aged mixture	Marshall properties	Stability, kN	17.4
		Flow, mm	3.05
		Air voids, %	5.21
		Bulk density, gm/cm <sup>3</sup>	2.329
		Maximum theoretical density, Gmm, gm/cm <sup>3</sup>	2.465

## 2.2. Rejuvenator Agents

Two types of liquid bitumen have been implemented as recycling agent based on available literature and experience, (Sarsam and AL-Janabi, 2014); (Sarsam and Saleem, 2018-a); and (Sarsam and Mahdi, 2019-a). The rejuvenators implemented are medium curing cutback MC-30 and cationic emulsion.



**Figure 1. Gradation of RAP (reclaimed) aggregate obtained from the field**

## 2.3. Cutback Bitumen

Medium curing cutback MC-30 obtained from Dura refinery has been implemented as one of the rejuvenator agents for recycling in this investigation. The properties of the cutback are shown in Table 2.

**Table 2. Properties of medium curing cutback as obtained from Dura refinery.**

Property	Test conditions	(ASTM, 2003) designation	Value
Kinematic viscosity	60°C	D2170	42
Flash point	—	3143	52
Distillate, volume percent of total distillate	225°C	D402	23
	260°C		47

	315°C		89
Residue from distillation	360°C	D402	63
Residue from distillation			
Viscosity	60°C	D2171	67
Ductility	25°C	D113	132

## 2.4. Emulsified Bitumen

Cationic emulsion obtained from the Ministry of Industry and Minerals has been implemented as one of the rejuvenator agents for recycling in this investigation. The properties of emulsion are listed in Table 3.

**Table 3. Properties of cationic emulsion as supplied by the manufacturer.**

Property	Test conditions	(ASTM, 2003) designation	Value
Say bolt Furol Viscosity	50°C	D245	235
Storage stability	24-h	D6930	0.7
Particle charge		D7402	Positive
Sieve test	—	D6933	0.063
Distillation: Oil distillate, by volume of emulsion, %	—		7
Residue, %		D6997	93
Tests on residue from distillation			
Penetration, 25°C	25°C, 100 g, and 5 S.	D5	57
Ductility	25°C and 5 cm/min	D113	59
Solubility in trichloroethylene, %	—	D2042	100

## 2.5. Recycling Process of RAP Mixture

Recycling process implemented in this investigation consists of 100% reclaimed pavement RAP and recycling agent mixed together at specified percentages according to the mixing ratio. First, RAP was heated to approximately 160°C, while the liquid asphalt was conditioned at room temperature of 25°C and added to the heated RAP at the desired amount of 0.5% by weight of the mixture and mixed for two min until all mixture was visually coated with recycling agent as addressed by (Sarsam and Saleem, 2018-b). The recycled asphalt mixture was prepared using two types of liquid bitumen: medium curing cutback and cationic emulsion. The rejuvenators implemented can reduce the viscosity of the aged bitumen and furnish more flexibility to the recycled asphalt concrete mixture, it can also increase the resilient strain.

## 2.6. Short-term Aging of Recycled Mixture

The recycled asphalt mixture with cutback bitumen exhibit poor adhesion due to the low viscosity of cutback asphalt, then it was decided to conduct the short-term aging to minimize the volatiles content and increase the viscosity of the cutback. The Recycled asphalt mixture was heated to 135°C to become loose and then, diffuses in shallow trays with 3 cm thickness and subjected to accelerated aging by laying inside an oven at 135°C for 4 hours as per Superpave procedure, (AASHTO, 2013). The asphalt mixture was stirred every 30 min during the short-term aging to prevent the outside of the mixture from aging more than the inner side because of increased air exposure. Samples recycled with cutback had experienced such aging process, while samples recycled with emulsion was not subjected to such process since it exhibit proper cohesion. Figure 3 exhibit the short-term aging process.



**Figure 2. Reclaimed asphalt concrete (RAP).**



**Figure 3. Short term aging of recycled RAP**

## 2.7. Preparation of Beam Specimen

Beam specimens with 400 mm length, 80 mm width and 50 mm depth have been prepared. A steel mold is manufactured to construct asphalt concrete beam specimens; the steel mold consists of four sides made from 127 mm standard C-channel steel section bonded together by steel bolts, and 10 mm steel base plate. The recycled asphalt concrete mixtures were subjected to static compaction using standard compression machine with 25.7 kPa capacity applied to a steel plate that covers the asphalt mixture to apply uniform load. The applied pressure is maintained at 25.7 kPa for 2 min at 140°C to achieve the target bulk density of 2.372 gm/cm<sup>3</sup> and the desired thickness. The obtained beam specimen has a standard dimension according to (ASTM, 2003). Figure 4 shows part of the prepared beam specimens and the preparation process. The mold was left to cool overnight and then, the beam was extruded from the mold. Details of obtaining the target density were published elsewhere, (Sarsam and Saleem, 2018-b).



**Figure 4. Preparation of the asphalt concrete beams**

## 2.8. Repeated Flexural Stresses Testing

The four-point loading system with free rotation of beam holding fixture at all loading and reaction point was implemented for the repeated flexural beam test. The purpose of using four-points loading was to get pure bending in the third middle area of the beam. The number of load cycles that caused distress of the beam were commonly considered as an indicator of micro-cracking potential. The details of the factorial variables in the experimental design of the flexural beam fatigue test are that the stress level is 138 kPa, which was selected as a target to represent medium traffic loading. Loading of 138 kPa was applied in the form of a rectangular wave with a constant loading frequency of 60 cycles per minute and loading sequence for each cycle is 0.1 second of load duration and 0.9 seconds of rest period. The vertical deflection during the test of the beam at the mid-span was measured with Linear Variable Differential Transformer LVDT. A range of stress

was selected so that the specimens would fail within a range of 100–100,000 repetitions. The test temperature of 20°C was implemented because the micro cracking usually occurs at an intermediate temperature of around 20°C. An aluminum steel road supporting the LVDT was fixed at the upper point of the beam to capture the difference in deflection. The repeated loading process was captured by digital camera to monitor the deformation throughout the test. The vertical deflection during the test of the beam at the mid-span was measured with a sensitive dial gage and the deflection at various time intervals was captured in the video and analyzed for finding strain at any number of cycles desired for every test. The beam specimens were tested in the chamber of the pneumatic repeated load system PRLS shown in Figure 5.

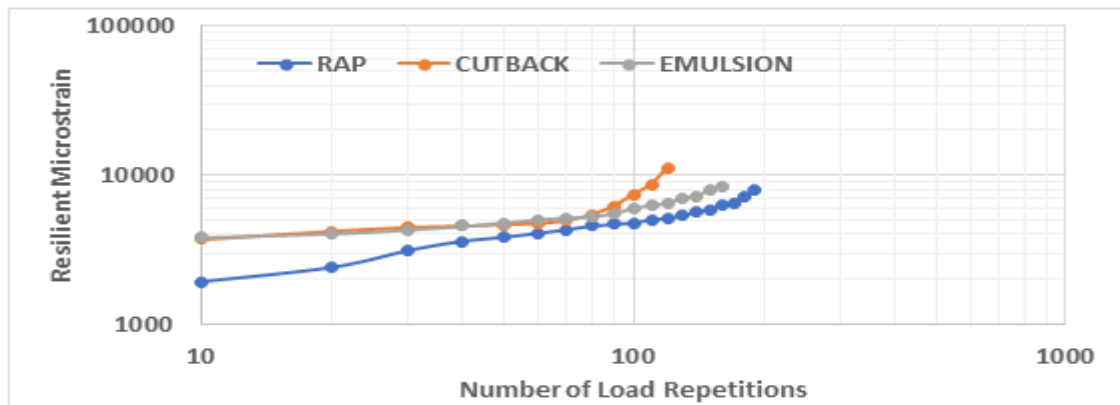


**Figure 5. Beam Specimen in the PRLS testing chamber**

### **3. RESULTS AND DISCUSSIONS**

#### **3.1. Influence of Rejuvenators on the Flexibility of Recycled Asphalt Concrete**

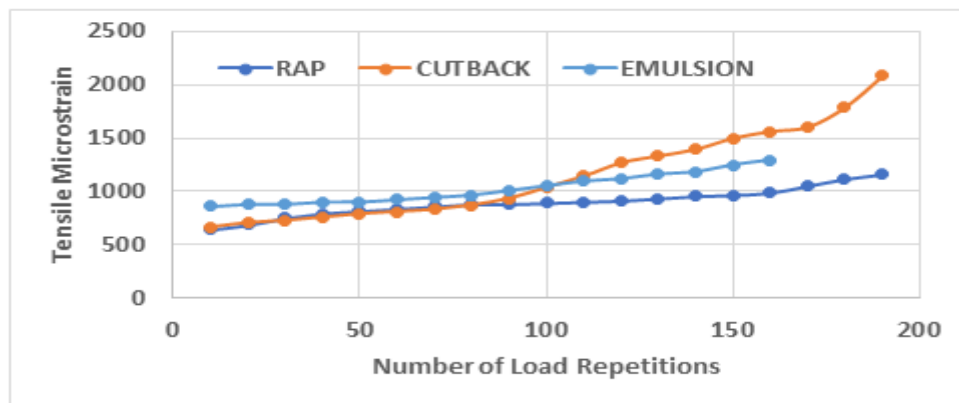
As demonstrated in Figure 6, the resilient deformation in terms of the change in microstrain increases gently as the number of load repetitions proceeds. It can be observed that the reclaimed asphalt concrete before recycling exhibit lower resilient deformation as compared to that of recycled mixture. This could be attributed to the stiffer nature of reclaimed mixture due to higher viscosity of the aged asphalt binder. Such finding agrees well with (Sarsam and Mehdi, 2019-b). When the rejuvenators are applied to RAP, more flexibility is initiated in the mixture due to the reduction in the viscosity of the binder. It may be noted that cutback treated RAP exhibit higher resilient microstrain than emulsion treated RAP. This may be attributed to the fact that the kerosene in the cutback bitumen was able to dissolve the aged binder in the RAP during the mixing period, while the emulsion could not do the same. On the other hand, the rejuvenator treated RAP exhibit lower resistance to the impact of load repetitions as compared to the case of reclaimed materials. The reduction in the service life is (36.8 and 15.7) % for cutback and emulsion treated RAP respectively as compared to reclaimed material. Similar finding was reported by (Behnood, 2019). This could indicate that 100 % of recycled RAP is not recommended for wearing course application based on the limitations of the present investigation.



**Figure 6.** Flexibility of Recycled Asphalt Concrete in terms of Resilient Strain

### 3.2. Influence of Rejuvenator Type on Tensile Strain

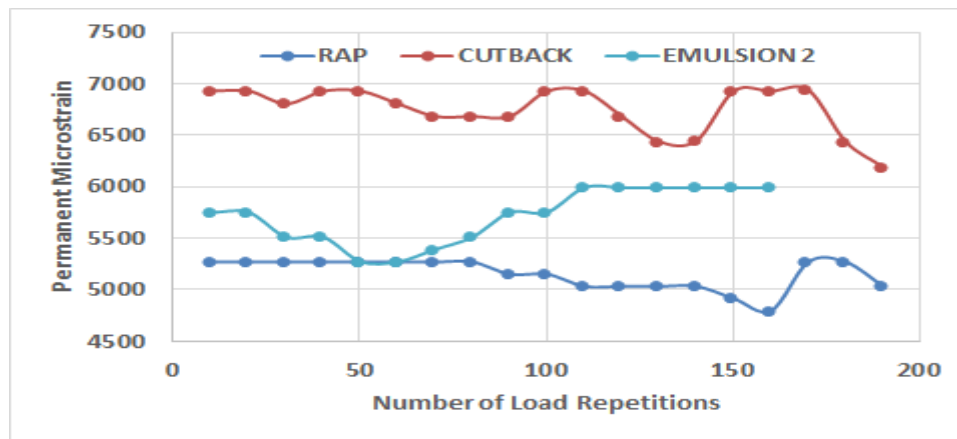
Tensile strain was measured at a stress level of 0.138 MPa, test temperature of 20°C, while the frequency of load application used is 1 Hz with load duration of 0.1 second and a resting period of 0.9 second. Tensile strain test was conducted on beam specimens of dimension (400 x 80 x 50) mm. To evaluate the resistance to total deformation, the tensile strain at 150 load repetition was selected as a reference for comparison. Figure 7 exhibits the effect of Rejuvenator on total tensile microstrain. It appears that the lowest tensile strain was obtained for reclaimed mixture as compared with recycled mixes, while the recycled mix with cutback bitumen exhibit higher tensile strain than recycled mix with emulsified bitumen. The tensile strain increased by (58 and 31) % for recycled mixtures with cutback and emulsion, respectively, as compared to that of RAP mixture. This could be attributed to added flexibility to the RAP by implication of rejuvenators.



**Figure 7.** Influence of Rejuvenators on Total Tensile Strain

### 3.3. Influence of Rejuvenator Type on Permanent Strain

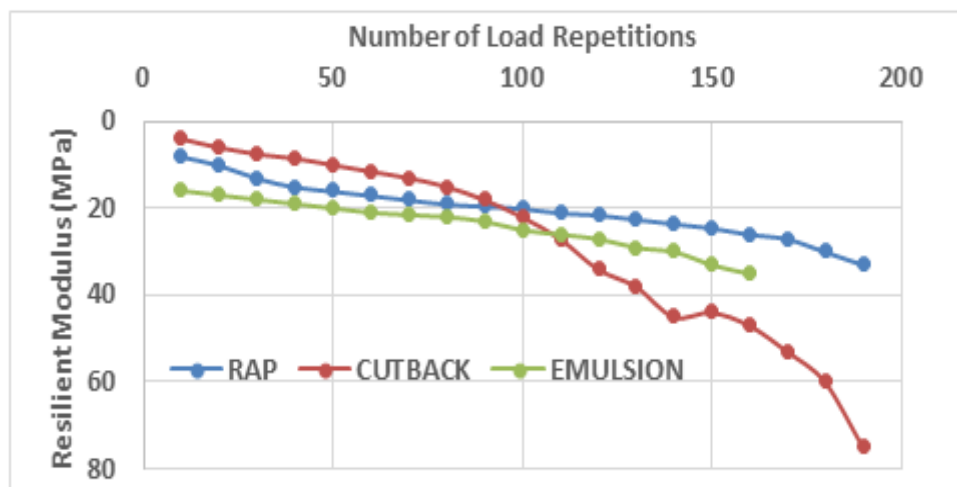
As demonstrated in Figure 8, the permanent microstrain exhibit no significant variation as the loading proceeds, this may be attributed to the fact that most of the permanent strain occurs at the early stage of load repetitions. It can be observed that higher permanent strain is associated with implication of rejuvenators. RAP treated with Cutback bitumen exhibit higher permanent strain as compared to emulsion treated RAP. This may be attributed to impact of kerosene in dissolving the aged bitumen of the RAP and decrease its viscosity and increase the flexibility of the RAP material during the mixing process. Similar findings were reported by (Lin et al, 2011) and (Sarsam and Saleem, 2019). The increment in permanent microstrain was (40.8 and 22.2) % for cutback and emulsion treated RAP respectively as compared to RAP material before recycling.



**Figure 8.** Influence of Rejuvenators on Permanent Strain

### 3.4. Influence of Rejuvenator Type on Resilient Modulus

Resilient Modulus  $M_r$  was measured at a stress level of 0.138 MPa and testing temperature of 20°C. Figure 8 exhibits the impact of Rejuvenator on  $M_r$  under repeated flexural stress. It can be noted that the  $M_r$  declines as the number of load repetitions proceeds. The  $M_r$  for reclaimed mixture under flexural was higher than  $M_r$  for recycled mixture with cutback and emulsion. On the other hand,  $M_r$  for recycled mixture with cutback was higher than that of recycled mixture with emulsion up to 100 load repetitions, then it declines sharply. This behavior may be attributed to the more flexible nature exists in case of cutback treated RAP. The percent of reduction in  $M_r$  under 150 repetition of flexural stress was (79 and 34.7) % for recycled mixtures with cutback and emulsion respectively as compared to that of the RAP mixture. This may be attributed to the higher viscosity of the aged binder in the reclaimed material which exhibit stiffer mixture as compared to the case of recycled mixtures. Such finding agrees well with the work reported by (Al-Qadi et al, 2007), and (Sarsam and Mahdi, 2019-b).



**Figure 8.** Resilient Modulus  $M_r$  for mixtures.

## 4. CONCLUSIONS

Based on the testing program, the following conclusions may be drawn:

1. Implementation of rejuvenators in reclaimed asphalt concrete material exhibit positive influence on the flexibility of recycled asphalt concrete by increasing the resilient strain.
2. The reduction in the service life is (36.8 and 15.7) % for cutback and emulsion treated RAP respectively as compared with reclaimed material. 100 % of recycled RAP is not recommended for wearing course application.
3. The increment in tensile strain under repeated flexural stresses at a temperature of 20°C is (58 and 31) % for recycled mixture with cutback and emulsion respectively as compared with that of the reclaimed mixture.
4. The percent reduction in resilient modulus  $M_r$  under repeated flexural stresses is (79 and 34.7) % for recycled mixtures with (cutback and emulsion) respectively as compared to that of the reclaimed mixture.
5. The increment in permanent microstrain was (40.8 and 22.2) % for cutback and emulsion treated RAP respectively as compared to RAP material before recycling.

6. It is recommended to construct a trial section using recycled 100% RAP with cutback and emulsion to verify the field performance in mixing, spreading, and serviceability of the mixture.

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