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Sustainability of Asphalt Paving Materials Containing Different Waste Materials

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Abstract. Generating recycled tires, disposable plastic bottles and waste engine oil are important problem in Iraq and there is need to solve it. The waste materials can be considered as alternative materials in road pavement technology and the using of these materials would be a solution to converse the environment from pollution in one hand and modifying the asphalt paving materials on the other hand. The two waste materials (recycled tire rubber and plastic bottles) have been evaluated as supplementary materials by with (3, 6, 9 and 12) % by total weight of aggregate retained on 2.36 mm sieve. The waste engine oil was used as an asphalt cement modifier and it was added as partial replacement of asphalt content by with (5, 10 and 15) % by weight of asphalt. This experimental work aimed to use Marshall properties, indirect tensile strength, and immersion-compression and wheel track tests to determine the influence of different waste materials on the performance of compacted asphalt paving materials of highways. The study concluded that the 12%PB mixtures seem to produce a reduction in the density and rut depth, an increase in air void, VMA, Marshall stability and indirect tensile strength. The recycled tires with 9% by total weight of aggregate retained on (2.36mm) sieve exhibited high resistance to water damage. The indirect tensile strengths of the asphalt mixtures incorporated waste oil engine were lower than those of the control mix and these modified mixtures have a good resistance to moisture damage.

Key words: Plastic bottles, indirect tensile strength, Rutting, Recycled tire rubber, Waste engine oil and Wheel track test

1. Introduction

In ecent decades the large efforts have been spent to define the sustainability concepts and to incorporate more sustainable practices in a systematic and organized manner [1]. To understand the pavement sustainability, it is essential to consider the entire pavement life cycle (shown in Fig.1), which can be divided into the following phases: production of materials, flexible pavement design, construction techniques, use phase, maintenance and preservation, and end of life cycle.

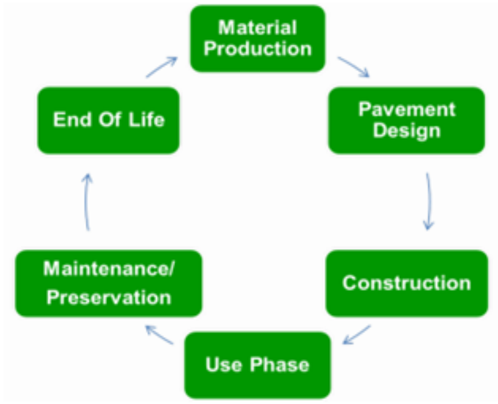

Figure 1. Pavement life cycle phases

The sustainable pavement includes the using of waste materials in asphalt mixtures production stage and flexible construction to conserve the environment, increasing the pavement cycle life and reducing the maintenance cost. This paper includes the investigation of the Marshall characteristic, tensile strength of asphalt mixture incorporating three waste materials (plastic bottles, recycled tire rubber and waste engine oil), moisture damage and rut depth of asphalt mixture have been evaluated. The using of tire rubber in preparing of asphalt mixtures is common and more active to be used in construction of highway pavement in hot region. The addition of rubber to asphalt materials will improve the resistance of blended asphalt to temperature susceptibility and rutting [2], [3].

Waste tire materials can be added to asphalt mixture by two methods which are dry and wet processes [4], [5]. In the wet process, the rubber will be as modifier to native asphalt , while in the dry process, the rubber particles are as a partial replacement of fine aggregate materials in the asphalt mixtures [5]. In both cases, the tire rubber materials modify the asphalt cement and concrete mixture as a whole [6].

One of waste materials can be used as alternative one to new pavement materials is plastic bottle, and it is mostly made by Polyethylene Terephthalate (PET) [7]. Today, reuse of these materials as construction material in pavement projects will conserve the environment and prevent environmental pollution [8]. On the other hand, by increasing the number and frequency of trucks which have high axle load , design life of flexible pavement will reduce. This increasing in axle loading requires more pavement thickness with additional construction cost. Thus, using waste materials might be a better solution to overcome the pavement deterioration problem. The waste materials can be added to asphalt mixtures by two methods : wet or dry processes. In wet process the materials will be blended with asphalt to form modified asphalt before mixing with aggregate particles while in the dry process the additive is adding to the asphalt mixtures directly during the preparation operation [9].

Plastic bottle wastes in chemical composition are rich in polymers [10]. These materials might be blended with asphalt in wet approach or it can be considered as fine aggregate materials in dry approach [11]. High density polyethylene (HDPE) is better than low density polyethylene (LDPE) in enhancing asphalt concrete mixture properties [12]. Added plastic materials reduce the temperature susceptible of modified asphalt [13]. HDPE with hot mix asphalt increased resistance to deformation and gave higher Marshall stability and lower Marshall flow values [14].

The using of rubber in construction of asphalt layers for flexible pavement improves the skid resistance of a pavement surface . Also, the asphalt concrete mixtures contained the rubber materials exhibited high shear strength under traffic loading [15]. Some other benefits of using rubber in pavement construction is decreasing of temperature susceptibility, and rutting and increasing of stability and reduced flow value by employing of 10% rubber and improving stripping resistance [16].

Waste oil that is throw away in landfill and causes adverse impact on the environment [17] and [18]. Waste oil is added to asphalt mixture in a liquid case. It can pour directly to heated aggregated and The mixing temperature is about 150^{o}C [19]. Nurul Hidayah et al. [18] evaluated the mixing temperature 160^{o}C with mixing speed of 600 rpm by using special mixer. Waste Engine Oil (WEO) can be employed as a modifier of asphalt cement because there is good confirmation in chemical composition of asphalt cement and engine oil [20].

2. Experimental Work

2.1 Materials

2.1.1 Asphalt Cement

One type of asphalt was employed in this study which is (40-50) penetration grade obtained from Nasiyraa refinery. The asphalt characterizations were evaluated according to ASTM standard [21], and compared with Iraqi specification know as State Corporation for Roads and Bridge [22] . Table 1 presents the asphalt properties.

2.1.2 Coarse and Fine Aggregate

The aggregate employed in this study (coarse and fine) were provided in AL Najaf quarries. The aggregate gradation satisfies the requirements of surface course gradation Type III A as per SCRB specifications [22] . The aggregate properties are shown in Table2 while Table 3 shows the aggregate gradation used in preparing modified and unmodified mixtures.

2.1.3 Filler

Filler materials represent mineral particles that pass sieve no.200. Ordinary Portland cement was considered as a filler and it was brought from Najaf cement factory , with percentage of 7% by weight of total aggregate, which represent average value of SCRB specifications for type IIIA surface course [22]. Table 4 shows the properties of cement filler material.

2.2 Additive Materials

2.2 1. Waste plastic bottles

The samples of waste plastic bottles have been obtained from waste PET bottles, the bottles were divided into small parts then the parts were crushed and sieved to retain on No.8 (2.36 mm) sieve. In study different percentages of waste plastic bottles are adopted : 3, 6, 9, and 12 % by weight of aggregate particles passing No. 4 (4.75 mm) and retained on No.8 (2.36 mm) size.

2.2.2. Recycled Tires Rubber (RTR)

Recycled rubber is created by grinding recycled tire rubber (RTR) after stripping out steel reinforcement. It is brought from Al-Najaf tires factory. The physical properties of RTR are shown in Table 5. The recycled tires rubber (RTR) was used as replacement for aggregates passing sieve No.4 (4.75 mm) and retained in sieve No. 8 (2.36 mm) in asphalt mixture.

2.2.3. Waste Engine Oil (WEO)
The operation of blending (WEO) with asphalt used in this investigation was the wet process in which the (WEO) was added to the asphalt before the mixing the asphalt with the aggregate particles . The blending machine was used at a blending speed of 600 rpm at temperature of 160 ^{o}C for 30 minutes [20].The density of WEO was 0.83 g/cm^3 at 25^{o}C and the absolute viscosity at 60^{o}C was 2133 poise.

2.3 Marshall Mix Design

Marshall mix design method in accordance with (ASTM D6927) [21] was adopted to determine the optimum asphalt content of various asphalt mixtures. The Marshall specimens were compacted to 75 blows per face using the Marshall compactor to fulfill the design criteria of air voids that ranging between (3 to 5) %.Marshall stability and flow values have been determined at 60^{o}C temperature. The optimum asphalt content (OAC) percentages were determined for twelve asphalt mixtures with and without additives. Marshall properties of different asphalts are summarized in Table 6 as an average of three Marshall specimens.

Indirect Tensile Strength: The indirect tensile strength test was carried out **ASTM D4867** [21]. In this test, fabricated specimens are tested to determine their indirect tensile strengths using a Marshall loading frame fitted with 12.5 mm wide concave surface loading strips below and above the Marshall sample and the rate of loading was the same used in the Marshall Stability test, i.e. 50.8 mm per minute, and total number of samples are 36 samples at optimum asphalt content (%) for different modified and conventional asphalt mixes . The ITS value is calculated using the following formula :

$$ITS= \frac{2P}{\pi * t * d} \quad \ldots \quad (2)$$

Where:

ITS = indirect tensile strength (kPa);
P = failure load (N);
t= thickness of specimen (mm);
d= diameter of specimen (mm).

Table 6 summarizes the indirect tensile strength of different asphalt mixtures.

Immersion compression: Immersion-compression test was conducted in accordance with ASTMD1075 [21] to determine the numerical index of resistance of bituminous mixtures to the detrimental effect of moisture for various asphalt mixtures . The index of retained strength (IRS) was calculated as the percentage of the original strength that is retained after the immersion period as follows:

Index of retained strength, % = (S 2/S1)×100 … (3)

where: S1 = compressive strength of dry specimens (Group 1), and S2 = compressive strength of immersed specimens (Group 2).

The road pavement Iraqi specifications (SCRB-R9, 2003**)** [22] require the IRS value is more than 70%.

Wheel Tracking Test: The rut depth occurred in asphalt concrete mixture slab specimen was obtained by performing wheel track test as per AASHTO T324 [23]. In this test , slab samples were fabricated with specified dimensions and load was applied through a steel wheel by repeated back and forth movement along its length. Total load of 31 kg with a mean normal pressure of 5.6 kg/cm^2 was applied at the rate of 42 passes per minute. After conditioning of sample at 40°C, the load was applied for approximately 20,000 cycles, and, finally, the total rut depth was recorded. Three replicate samples were tested for each asphalt mixture type. The Wheel Track Apparatus (WTA) device had been found in National Center for researches and structural laboratories in Baghdad city as shown in **Fig. 2.** The rut depth values obtained by this test are reported in Table 6.

3. Discussion of Results

After implementing the above experimental works, four results have been obtained from the conduction of these experimental works. Firstly, the Marshall properties and air voids refer to Table 6 with 9% RTR , 12%PB and 5% WEO modified asphalt mixtures are best among other mixtures while 12%RTR , 3%PB and 15%WEO does not comply with the requirements of SCRB/R9 specifications for mixture properties used in the construction of surface course .

Secondly, **Fig. 3** indicates the average results of the indirect tensile strength (ITS) test for the surface course mixtures with different types of mix. In general, 9%RTR mixtures have the highest strengths than the other mixture types wearing course mixes. However, this figure reveals all modified mixtures give low tensile strength which shows lower resistance under tension stresses. The improvement in tensile properties for 9%RTR mixtures may be as a result of effect of rubber on asphalt tensile properties .

The index of retained strength (IRS) is good test to predict the asphalt concrete moisture damage. **Fig. 4** illustrates IRS values for all asphalt concrete mixtures. It can be noticed there is an increase of IRS values with the increasing of waste material percentages. It can be concluded that asphalt mixture contain the waste materials is more resistance to moisture damage than control ones . All asphalt mixtures studied in this paper exhibited index of retained strength percentages larger than 70% as reported in Table 6. Also it can be observed from Table 6 and **Fig. 4** that IRS value of modified asphalt mixtures containing 9RTR% is approximately 17% more than control ones.

Fig. 5 illustrates the influence of the selected three additives (RTR , PB and WEO) on rut depth. As it is clear from Fig. 4, the average rut depth of the 12%PB was lower than that of the HMA by about 49%**.** It can be concluded that the using of PB additive in the construction of surface course for the pavement structure decreases the rutting failure in comparison with using HMA. The possible reason to this reduction in rut depth value for mixtures contain 12%PB is the this additive will give the strength of the mixture by reinforcement the aggregate –asphalt structure.

Table 1. Properties of used Asphalt Cement

Property	ASTM Designation	Test Results	Requirements Penetration – Graded Asphalt Cement (40/50)
1.Penetration at 25 ^oC , (0.10mm)	D5	48	40-50
2. Ductility at 25 ^oC , (cm)	D113	110	>100
3.Specific gravity at 25 ^oC	D70	1.03	------
4.Flash point ,(^oC)	D92	275	>232
5.Solubility in trichloroethylene, (%wt)	D2042	99.37	>99

6.Residue from thin –film oven test - Retained penetration , % of original -Ductility at 25 ^{o}C, (cm)	D1754 D5 D113	68 57	>55 >25

Table 2. Physical Properties of Aggregates

Property	ASTM Designation	Test results	SCRB specifications
Coarse aggregate			
• Bulk specific gravity	C 127	2.614	….
• Apparent specific gravity	C 127	2.686	….
• Percent wear by Los Angeles abrasion , %	C131	22.7	30 Max.
• Soundness loss by sodium sulfate solution,%	C88	3.4	12 Max.
• Flat and elongated particles ,%	C 4791	5	10 Max.
• Degree of crushing, %	D5821	96	90 Min.
Fine aggregate			
• Bulk specific gravity	C127	2.664	….
• Apparent specific gravity	C127	2.696	….
• Sand equivalent, %	D2419	57	45 Min.
• Angularity ,%	C1252	54	….
• Clay lumps and friable particles, %	C142	1.85	3 Max.

Table 3. Selected Mix Gradation for The Type Iiia Mixes of Wearing Course

Sieve	19 mm	12.5 mm	9.5 mm	No.4	No.8	No.50	No.200
% Passing	100	95	83	59	43	13	7

Table 4. Physical Properties of Cement Filler

Property	Test method	Result
%passing sieve No.200	….	96
Specific gravity	ASTM C 128	3.13
Fineness(cm^2/gm)	….	3123

Table 5. Physical Properties of Recycled Tire Rubber

Tensile strength(MPa)	47
Melting point(^{o}C)	200
Specific gravity	1.13
Carbon black (%)	28
Ash at 550^{o}C	12

Table 6. Characterizations of Asphalt Mixtures

Mixture type	Marshall stability, kN	Marshall flow, mm	Bulk density, gm/cm^3	Air voids,%	Indirect tensile strength, kPa	Optimum asphalt content ,%	Index of retained strength,%	Rut depth (mm)
Control mix	11.2	3.3	2.322	3.92	1168	4.9	83	12.36
3%RTR	6.15	6.8	2.334	4.05	836	5.0	82	10.52
6%RTR	6.9	5.1	2.296	4.15	894	4.95	87	9.07
9%RTR	9.4	3.1	2.305	4.09	1422	5.12	96	8.12
12%RTR	8.1	4.3	2.311	5.10	853	5.10	88	7.27
3% PB	8.3	4.6	2.288	4.62	736	5.05	77	8.46
6% PB	8.6	3.9	2.270	4.71	1107	5.0	79	7.77
9% PB	8.9	3.1	2.272	4.77	841	4.95	83	7.16
12% PB	9.7	2.7	2.267	4.79	802	5.10	86	6.3
5%WEO	10.7	3.5	2.282	4.55	643	4.82	82	14.04
10%WEO	8.5	4.3	2.293	4.23	782	4.74	87	16.73
15%WEO	5.7	5.1	2.297	4.12	704	4.65	81	20.3
SCRB –R9 requirements (SCRB,2003)	Min 8 kN	2-4 mm	-------	3-5%			Min 70%	

Figure 2. Wheel Track Apparatus (WTA)

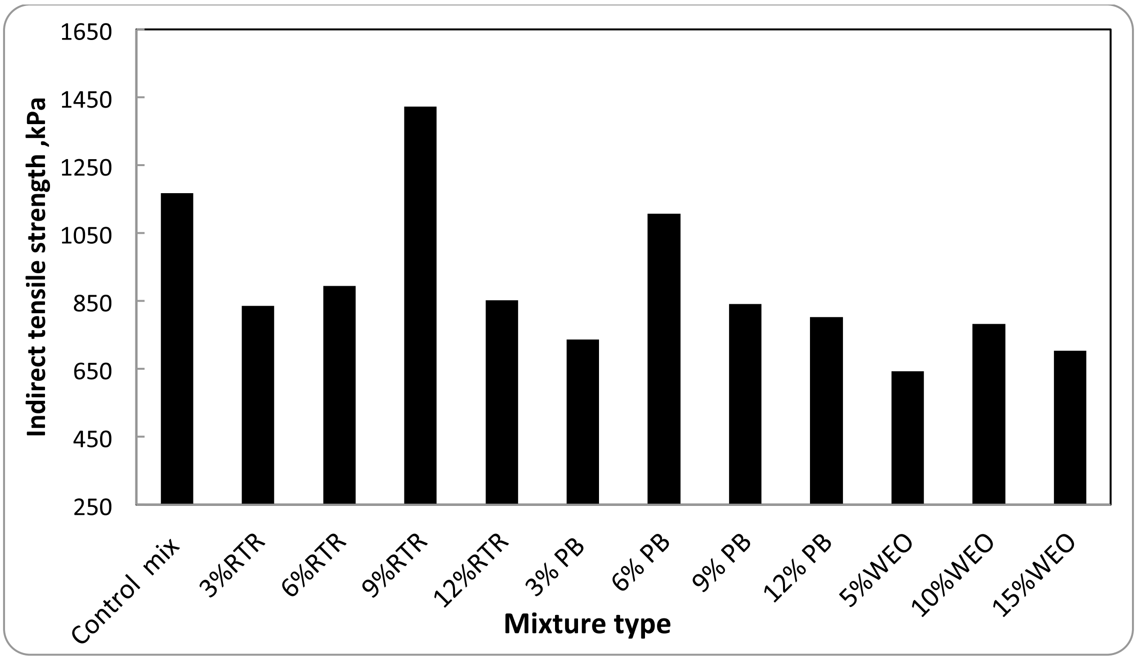

Figure 3. Effect of mix type on indirect tensile strength values.

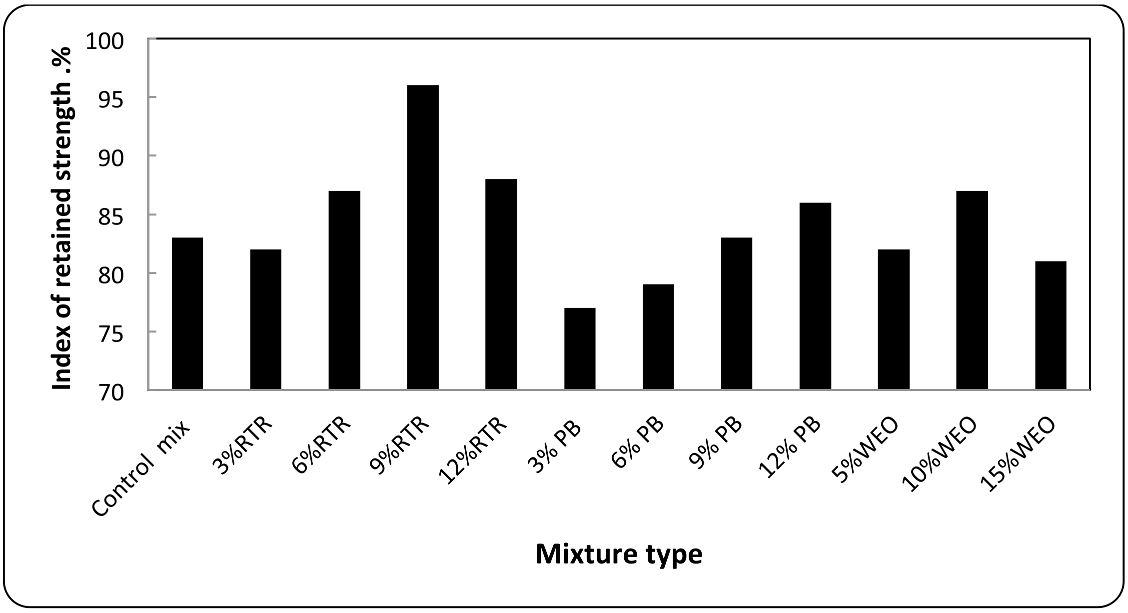

Figure 4. Effect of mix type on index of retained strength values.

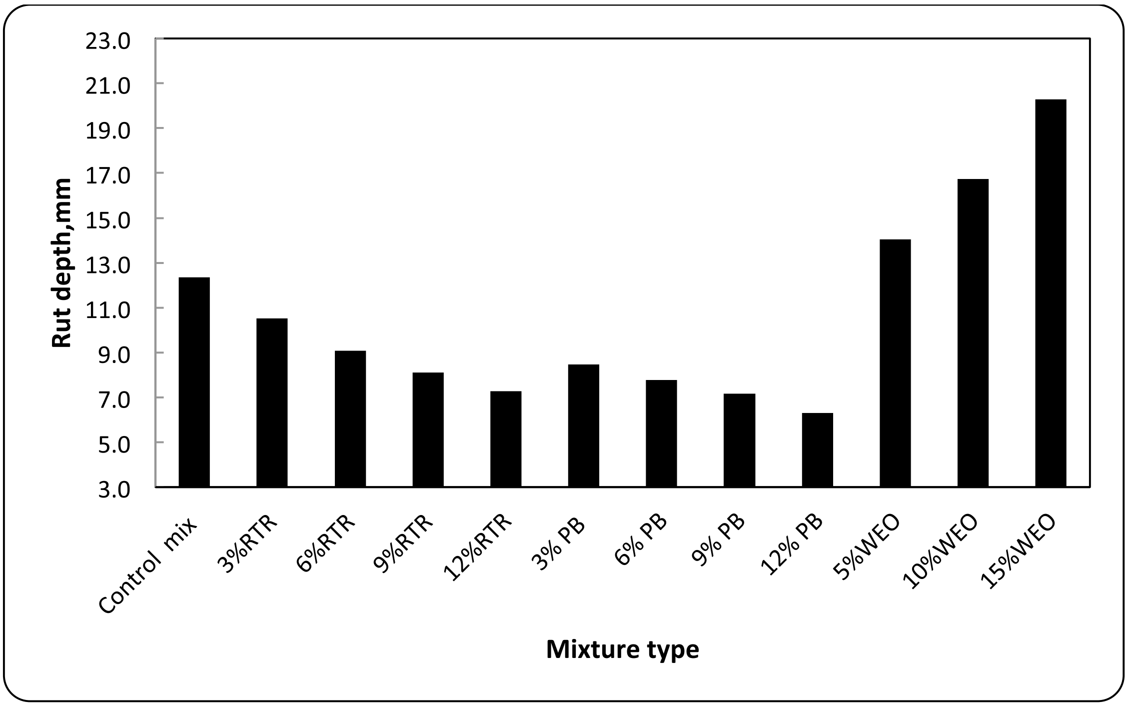

Figure 5. Effect of mix type on rut depth values.

4. Conclusion

According to the methodology used in this study , the main conclusions can be written as follows:

1. Mixtures containing 9% recycle tire rubbers had more tensile strength values compared to conventional mixture and the tensile strength trends initially increased by adding lower percentages of any waste materials and decreased at higher amount of three selected waste materials .
2. WEO mixtures showed to have lower OAC value among control and modified asphalt mixtures.
3. WEO prominently affects the properties of asphalt mixtures. It reduces the stiffness and increases the rut depth.
4. The mixtures containing 9 % RTR, 12%PB and 5%WEO showed higher Marshall properties and the asphalt mixtures fabricated with 9 % RTR appeared more resistance to moisture damage.

5. Acknowledgment

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References

1. FHWA . *Pavement Sustainability*. Tech Brief. FHWA-HIF-14-012. Federal Highway Administration, Washington, DC(2014).
2. A.Yilma , N. Degirmenci, *Possibility of using waste tire rubber and fly ash with Portland cement as construction materials* , Waste Management, **29**, 5, 1541-1546(2009).

3. L.Chitzan , C. L. Huang ,C. C. Shern, *Recycling waste tire powder for the recovery of oil spills* , Resources, Conservation and Recycling, **52**, 10, 1162-1166 (2008).
4. C. Ouyang, et al., *Compatibilizer in waste tire powder and low-density polyethylene blends and the blends modified asphalt*, J. of Appl. Poly. Sc., **123**, 1 ,485-492(2012).
5. H. Donza, O. Cabreraand E. F. Irassar, *High-strength concrete with different fine aggregate,* Cem. and Con. Res., **32**, 11, 1755-1761,(2002).
6. T. U. Jr Ganiron., *Effects of human hair additives in compressive strength of asphalt cement mixture*, Int. Jour. of Adv. Sc. and Tech., **67**, 11-22 ,(2014).
7. B.Shi, H.Liang, T.B. Kuhn, L.K. Duffy,. *Surface properties of cell-treated polyethylene terephthalate*. Amer. Jour. of Bioch. and Biotech, **2** ,4, 170-174 (2006).
8. M. Siddiqui,. *Conversion of hazardous plastic wastes into useful chemical products*, Jour. of Haz. Mat., **167**(1-3), 728-735,(2009).
9. T. Moghaddam, M. Karim, and T.Syammaun, *Dynamic properties of stone mastic asphalt mixtures containing waste plastic bottles,* Const, and Build. Mat., **34**, 236-242, (2012).
10. Z. Kalantar, M. Karim, A. Mahrez, *A review of using waste and virgin polymer in pavement,* Const. and Build. Mat., **33**, 55-62, (2012).
11. Y .Huang, R. Bird, O. Heidrich, *A review of the use of recycled solid waste materials in asphalt pavements*, Resources, Cons. and Recy., **52**, 1, 58-73, (2007).
12. M.Aziz, M. Rahman, M. Hainin, W. Bakar, *An overview on alternative binders for flexible pavement*, Construction and Building Materials, vol. 84, 315-319, (2015).
13. K.Moon , A. Falchetto, M. Marasteanu, M. Turos, *Using recycled asphalt materials as an alternative material in asphalt pavements*, KSCE J. of Civ. Eng., **18**, 1, 149-159, (2014).
14. R. Vasudevan, A.. Sekar, B. Sundarakannan, R. Velkennedy, *A technique to dispose waste plastics in an ecofriendly way–Application in construction of flexible pavements*, Const. and Build. Mat., **28**, 1, 311-320, (2012).
15. N. Mashaan , M. Karim, *Waste tyre rubber in asphalt pavement modification*, Mat. Res. Inn., **18**, 6, S6-6, (2014).
16. A. Modarres, P. Ayar, *Comparing the mechanical properties of cold recycled mixture containing coal waste additive and ordinary Portland cement*, Int. Jour. of Pav. Eng., **17**, no. 3, 211-224, (2016).
17. R. Romera, A. Santamaría, J. J. Peña, M. E. Muñoz, M. Barral, E. García, and V. Jañez, *Rheological aspects of the rejuvenation of aged bitumen*, Rheol. Acta, **45**, 4, 474–478, (2006).
18. M.K Hidayah., M.R. Hainin, N.A. Hassan, and M.E. Abdullah. Rutting ,*Evaluation of Aged Binder Containing Waste Engine Oil*. Adv. Mater. Res.911: 405–409,(2014).
19. C.D. Dedene. *Investigation of Using Waste Engine Oil Blended with Reclaimed Asphalt Materials to Improve Pavement Recyclability* .Master Thesis. Michigan Technological University(2011).
20. X. Jia, B. Huang, B. F. Bowers, and S. Zhao, *Infrared spectra and rheological properties of asphalt cement containing waste engine oil residues,* Constr. Build. Mat., **50**, 683–691, (2014).
21. ASTM Standards, *Roads and Paving Materials.* Annual Book of the American Society for Testing and Materials Standards, Section 4, Vol. 04-03,(2009),.
22. SCRB/R9. *General Specification for Roads and Bridges, Section R/9, Hot-Mix Asphalt Concrete Pavement*, Revised Edition. State Corporation of Roads and Bridges, Ministry of Housing and Construction, Republic of Iraq(2003).

IOP Conf. Series: Materials Science and Engineering **454** (2018) 012176 doi:10.1088/1757-899X/454/1/012176

23. AASHTO, *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*. 5 th edition , American Association of State Highway and Transportation Officials, Washington, D.C., USA(2007). .