MOISTURE DAMAGE AND FATIGUE EVALUATION OF HOT MIX ASPHALT (HMA) CONTAINING RECLAIMED ASPHALT PAVEMENT (RAP) AND POLYTHENE BAGS (LDPE)

Arshad Hussain[1], Sami ud Din[2], M. Adam Khan[3], Fazal Haq[4], Rida Asim[5]

[1]Assistant Professor, National Institute of Transportation, School of Civil and Environmental Engineering, National University of Sciences and Technology, Islamabad,
[2,3,5]Graduate Student, NUST Institute of Civil Engineering, School of Civil and Environmental Engineering, National University of Sciences and Technology, Islamabad,
[4]Post-Graduate Student & Research Assistant, National Institute of Transportation, School of Civil and Environmental Engineering, National University of Sciences and Technology, Islamabad, PAKISTAN.

[1]drarshad@nit.nust.edu.pk, [2]sdin.bece13nice@nice.nust.edu.pk, [3]mkhan.bece13nice@nice.nust.edu.pk, [4]fhaq.tn15@nit.nust.edu.pk, [5]rasim.bece13@nice.nust.edu.pk

ABSTRACT

Transportation infrastructure plays a key role in the everyday life of social beings. For its design, highway agencies focus on appropriate and cost-effective design techniques, which depends upon the selection and proportion of binder and aggregate. These techniques include the use of Reclaimed Asphalt Pavement (RAP), which is being used for the last many years and provides the opportunity to conserve our natural resources by using waste materials for a useful purpose, meeting economic and environmental friendly needs of a country. Same is the case for Polythene Bags (LDPE: Low-density polyethylene), which is used extensively all over the world for carrying shopping items. These polythene bags can be used in HMA to lessen the bitumen quantity. This project is based on evaluating the performance of Hot Mix Asphalt (HMA) by adding different contents of RAP and LDPE as a replacement of bitumen. The RAP contents used were 10%, 20%, 30% and 40%. Performance testing was done after finding out the Optimum Bitumen Content (OBC), volumetric, stability and flow of RAP containing mixtures, by preparing two types of samples for each mentioned RAP percentages, one having 0% LDPE, while another with replaced 4% LDPE of OBC. Performance testing included Indirect Tensile Strength (ITS) Test for Moisture susceptibility and Indirect Tensile Fatigue Test (ITFT) for Fatigue performance of HMA using Universal Testing Machine (UTM). It was noted that 20% RAP with 4% LDPE as a replacement of bitumen can be used which would give better properties than control mix having only virgin materials with 0% LDPE. Cost estimation showed 21.8% reduction in cost by adding the recommended combination.

Key words: Hot Mix Asphalt (HMA), Reclaimed Asphalt Pavement (RAP), LDPE, Polythene bags, Fatigue, Moisture damage.

INTRODUCTION

A practical and proficient transportation framework is the foundation of any nation's economy. Better transport system not only lead to the development of a country but also helps in increasing countries economy. In short the better the transportation system, the more prosperous would be the country.

RAP is being wasted on dump sites, which not only affects the soil but also the environment because of oxidations and fumes released by it. The utilization of RAP in various road

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projects aids road authorities to attain their objectives of a sustainable road transport structure by decreasing waste products and resource consumption. The utilization of RAP in HMA has economic and environmental friendly. It provides a mean to preserve fading resources of non-renewable petroleum products and aggregates in addition to saving disposal fees and dropping the adverse impact of landfills on our environment. RAP can be recycled not just for the asphalt it has but also for the aggregate, that is to be mixed in the central mixing plant with virgin aggregate and new binding material to form a recycled HMA.

The generation and utilization of polythene bags is expanding massively with the progression of time. When plastic bags are dumped, it does not deteriorate actually and remains in the earth influencing the natural framework. Plastic bags chemically consists of two elements i.e. carbon and hydrogen and are an oil based product. The burning of these polythene bags yields dioxin, which is an extremely toxic chemical. Dioxins are potentially cancer causing chemicals, which interfere with the system of endocrine gland, results in hormones production, and affect both the immune and reproduction system. Residue from burning pollutes the soil and groundwater and can enter the food chain of human via livestock and crops. Unburnt portions of the plastic become litter on the ground and in drainage systems, rivers and lakes. It not only affects the marine life but is also the major factor of failure of drainage system. So the world is interested in using the polythene bags for some beneficial purpose.

Moisture damage to HMA results in gradual loss of strength over time, which may cause stripping, the phenomena in which aggregates are detached from asphalt cement, leading to development of rutting and shoving in the wheel paths. Therefore, it is necessary to determine that whether the designed pavement is capable to resist damage from presence of moisture. Moisture damage can be evaluated through ITS test by determining the tensile strength of asphalt mix both conditioned and unconditioned. It consists of loading the specimen diametrically until cracking, the more the peak value of loading the more will be the strength of asphalt mix.

Fatigue cracking in flexible pavement refers to the phenomena of formation of interconnected cracks in asphalt pavement due to application of repeated loading. Fatigue is affected by mode of loading, stresses induced in pavement, loading pattern and rest period and mixture variable. The load applied produces horizontal tensile stress and vertical compressive stress along the diameter of specimen. Stress is maximum at the center, the strain can be calculated by assuming the material to be homogenous, force is line loading & there are plane stress conditions.

The advantages of ITS test and ITFT is its simplicity, the equipment can be used for other test also, field cored specimen can also be tested, there is less variability in results for same type of mix.

This research focus on determining optimum LDPE% that can replace bitumen content and optimum RAP% in HMA, so as not to affect the performance of pavement in term of moisture damage and fatigue at the other hand fulfilling the reuse of waste product.

RESEARCH OBJECTİVES

The main objective of this research is to use RAP and Polythene Bags in HMA. The objectives are as follows:

1. Fatigue evaluation of HMA containing RAP with and without Polythene bags.
2. Moisture susceptibility of HMA containing RAP with and without Polythene bags.

3. To use RAP and Polythene bags in making of asphalt pavements, to achieve the goal of reducing costs associated with roads construction.
4. To achieve these goals by not affecting the overall performance of the pavement.

LITERATURE REVIEW

Permanent deformation, temperature and overloading are various factors for failure of HMA pavements. Polymer modified asphalt concrete have been developed in recent years to address the pavement performance issues by taking into account the traffic loads as well. Numerous waste materials result from manufacturing operations, service industry and household. Increase in growth rate of population increased the industries production of various types of waste materials like blast furnace slag, plastics etc. These problems are faced more by developing countries. One solution to this problem is recycling waste into useful product.

RAP is an excavated or milled asphalt pavement, which is crushed and sieved into different sizes to meet specified grading requirements. RAP is being utilized in different countries in different ranges, depends on the country requirements. It normally ranges from 10-40 %. It can also be used in more amounts to about 50%, but then different problems occur with the pavement. RAP aggregate is finer than virgin, so it would beneficial in producing mixtures with fine gradation. (Januszke and Holleran, 1992) found out that introducing 30% RAP to HMA increase the resistance of the specimen to permanent deformation. It has lower permanent deformation than the conventional virgin aggregates specimens. (Kandhal et al.,1995) have deeply evaluated 5 projects, each comprising of recycled asphalt- concrete section and a control section, in which it was deduced that there was no such difference in its properties after being in service for 1.5 to 2.5 years with no significant fatigue cracking, rutting and raveling based on visual inspection. (Kiggundu and Newman, 1987) deduced that the mix having recycled asphalt binder, ages at a reduced rate than that of virgin mix. The reason may be, that the RAP material's slower rate of aging due to the already aging been happened to it.

Numerous researches have been carried out to check performance of pavement incorporating different percentages of LDPE. Some important studies that discussed the use of polymer in HMA include (Fawcett and McNal-ly, 2000) and (Yousefi et al., 1997).

Moisture susceptibility can be termed as loss in durability and strength of asphalt pavement and is due to the interaction of moisture with fine aggregate and binder. Less the bonding between aggregate and binder, more is the potential for moisture induced damage (Ahmed, 2014). Per (O'Sullivan, 2009), moisture present in air void of pavement is the potential cause of moisture induced damage. The damage reduces the strength and durability of pavement therefore must be properly checked to ensure long term performance of asphaltic pavement. Two types of moisture induced failure are commonly related. Cohesive failure, related to reduced bond strength of binder and Adhesive failure, which is in between binder and aggregate. (Zollinger, 2005). Per (Shrum, 2010), the reduced compaction temperature leads to moisture damage, as moisture present in aggregate is not sufficiently dried, leading to its damage, adequate moisture damage test must be performed to ensure better performance of pavement.

In 1998, Maine department of transportation recommended the Tensile Strength Ratio (TSR) of conditioned sample to an unconditioned sample as most appropriate measure of moisture damage to pavement. ITS test is easy to perform and very appealing. The specimen to be tested is easy to prepare.

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According to (Monismith et al., 1985) fatigue cracking reduces the life of pavement. The magnitude, frequency of load application, and the duration of load application was later identified to have major effect on pavement performance. (Sousa et al., 1998) determined the influence of aggregate gradation on the fatigue life of asphalt mixes by conducting four-point bending fatigue tests. They concluded that fine aggregate gradations seem to have better performance in fatigue than coarse gradations, due to higher requirement of binder content in those mixes. Increasing the binder content, increases fatigue life and decreases stiffness. The decrease in stiffness could be catered by the increased stiffness of the RAP binder. The fatigue life of pavement measured from ITFT is generally less than other methods to determine fatigue life (Porter and Kennedy, 1975). The micro-cracks present in pavement joins up to form macro cracks under the effect of repeated loading, this phase is known as crack initiation. After crack initiation phase, these cracks join up and lead to formation of major cracks in pavement (Lytton et al., 1993).

RESEARCH METHODOLOGY

Virgin aggregate was collected from Margalla hills crush plant site, Milled RAP was collected from Islamabad-Lahore Motorway (M-2) section, bitumen of grade 60/70 was collected from Attock Refinery Limited (ARL), while Polythene bags (LDPE) were collected from dump site of Islamabad near I-9 sector. Asphalt content in RAP was determined by ignition method with ASTM D 6307 – 98 and it was found that collected RAP contain 4.3% of bitumen. Compulsory tests on aggregate and bitumen were conducted according to their respective ASTM designations and all the results were according to the required criteria. Recovered bitumen from RAP were also tested for Penetration and Ductility and found out that by using the 20% of RAP, bitumen remains within the range of 60/70 grade. After that Marshall specimens were prepared for finding OBC of samples containing RAP only. These OBC's were then used to prepare samples for performance tests, two types of mixes were prepared, one having specified percentages of RAP only while other having RAP plus 4% LDPE (% by weight of OBC) as replacement of bitumen content. At last these samples were tested for moisture susceptibility and fatigue.

Gradation Selection

The gradation selected was NHA-B class gradation for surface course mix according to NHA (1998) specifications, the nominal maximum size for which is 19mm (3/4") according to MS2, and by adding varying percentage of RAP Aggregate i.e. 0%, 10%, 20%, 30%, 40%, percent passing against each sieve was obtained and plotted against sieve sizes which are tabulated in Table 1 and shown in Figure 1.

Table 1. Percent passing against each sieve in NHA-B gradation

Sieve Dia (mm)	% Passing						
	NHA B lower limit	*NHA B upper limit*	*Mid gradation selected*	*10% RAP*	*20% RAP*	*30% RAP*	*40% RAP*
19	100	100	100	100	100	100	100
12.5	75	90	82.5	83.74	84.41	85.32	86.33
9.5	60	80	70	70.53	70.884	71.11	71.33
4.75	40	60	50	50.3	50.77	50.89	51.11
2.38	20	40	30	31.55	32.65	33.76	34.67
1.18	5	15	10	10.8	11.66	12.87	13.87
0.075	3	8	5.5	5.03	5.36	5.46	5.987

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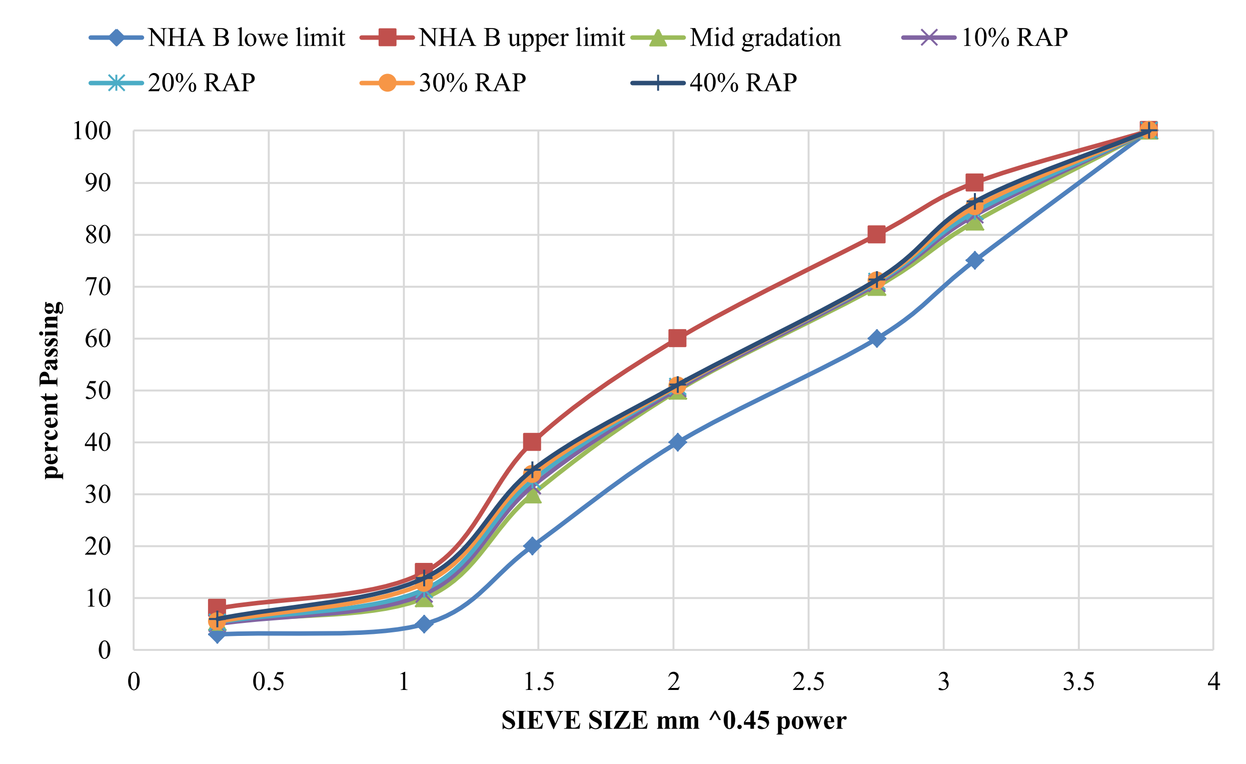

Figure 1. Plot of NHA-B gradation along with RAP percentages

Test on Modified binder (Bitumen+ LDPE)

Different tests were performed on modified bitumen by adding different contents of LDPE by weight of bitumen to the virgin bitumen and penetrations (ASTM D5 2006), softening point (ASTM 36 1995) and ductility (ASTM D113 2007) tests were carried out and it was concluded that increasing LDPE content reduces the penetration value making the binder harder, increases the softening point, while decreases the ductility values. Also, all the ductility values are in the range of 100 cm so it's okay to use LDPE content in bitumen. Results are tabulated in Table 2 and respective graphs are shown in Figures 2, 3 and 4.

Table 2. Test Results of Modified Bitumen

% of LDPE in bitumen	*Penetration Value*	*Softening point*	*Ductility*
0%	69	48	116
1%	67	49	118
2%	65	51	113
3%	64	52	111
4%	62	53	107
5%	59	56	106
6%	57	58	100

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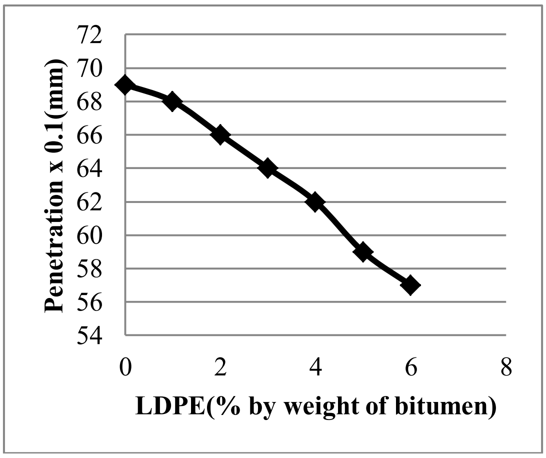

Figure 2. Penetration vs. LDPE

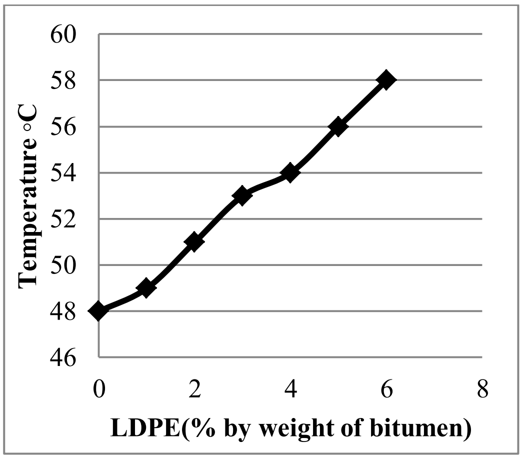

Figure 3. Temperature vs. LDPE

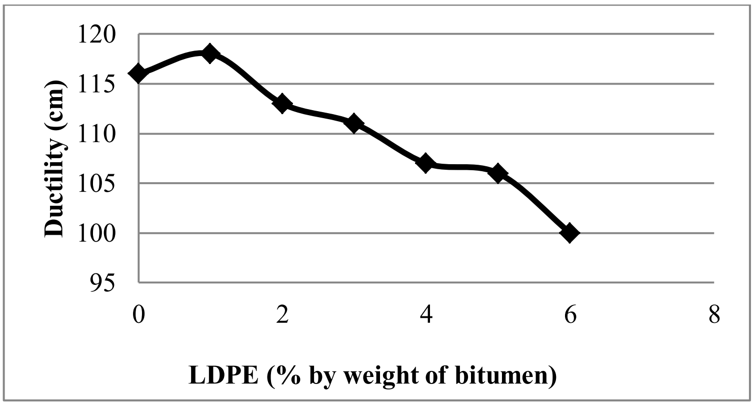

Figure 4. Ductility vs. LDPE

RESULTS AND ANALYSIS

Moisture Induced Damage (ITS) Test Results

Samples were made to be tested for ITS according to ALDOT 361-88. For HMA containing different contents of RAP only, two samples were made for unconditioned testing and two for conditioned testing, for each RAP content. Unconditioned testing involved the requirement of keeping the specimen at 25°C for one hour and then to be tested, while the conditioned samples involved the warm soaking for 24 hours at 60°C in water bath and then kept at 25°C for an hour right before the test. Same numbers of specimens were also made for the HMA containing different contents of RAP and 4% LDPE as a replacement of bitumen. Conditioned and Unconditioned tests were performed on them, the results of ITS tests are tabulated in Table 3.

The ITS of mix increases with increasing RAP content. This can be attributed to the lattice formation of RAP aggregate, since RAP aggregate got coated with RAP bitumen leading it to have more strength. Similar type of results was obtained by (Auranzeb, 2014). Minimum TSR value of 80% is also qualified for all mixes. The TSR value increases as RAP content increases, since the RAP contained hardened asphalt, which becomes more viscous as the time passes, and the sample having more viscous material perform better under tension, accordingly this will lead to less reduction in tensile strength when exposed to high temperature and moisture conditioning. The results of TSR are obtained as per findings of (Al-Rousan, 2008).

For samples containing LDPE, the ITS value also increases. These results are consistent with the findings of (Khan et al., 2009) and (Jain et al., 2011). The possible reason may be the provision of rougher surface texture for aggregate by LDPE, enhancing mix engineering properties due to improved adhesion between asphalt and aggregates. But these samples are slightly more susceptible to moisture as compared to samples containing RAP only.

Table 3. ITS Results

RAP content (%)	*S1 (kPa) [0% LDPE]*	*S2 (kPa) [0% LDPE]*	*TSR =S2/S1 [0% LDPE]*	*S1 (kPa) [4% LDPE]*	*S2 (kPa) [4% LDPE]*	*TSR =S2/S1 [4% LDPE]*
0%	795.56	758.5	95.34	832.1	787.70	94.67
10%	796.5	778.51	97.74	835.566	812.308	97.2
20%	807.67	793.79	98.28	850.388	830.63	97.67
30%	809.17	800.25	98.89	888.15	874.6	98.47
40%	816.39	808.79	99.06	891.17	878.95	98.62

S1= Average Un-Conditioned Tensile Strength, S2= Average Conditioned Tensile Strength

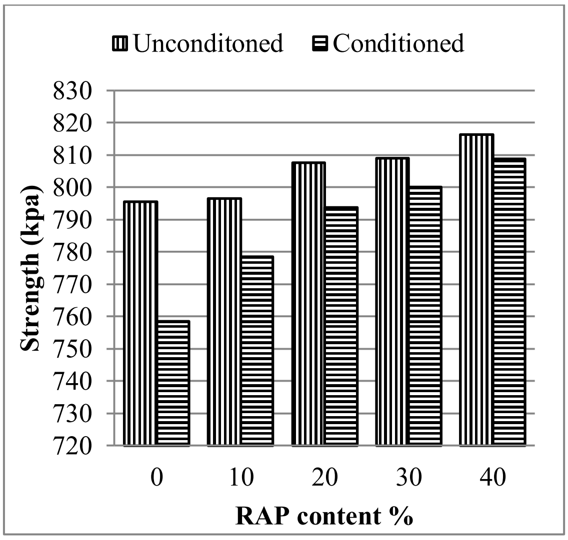

Figure 4. Strength of HMA containing RAP

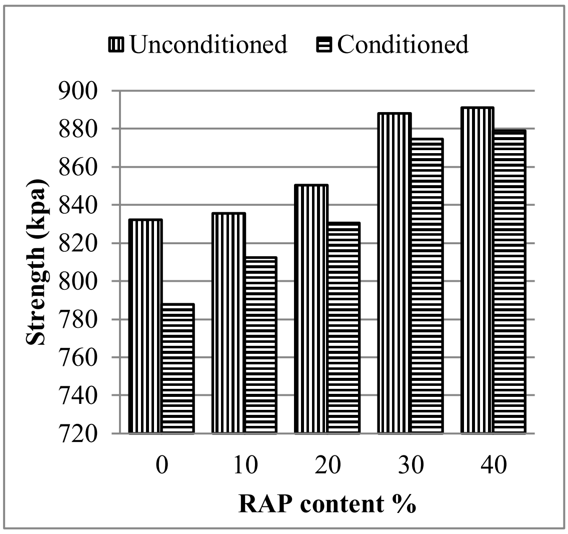

Figure 5. Strength of HMA containing RAP & LDPE

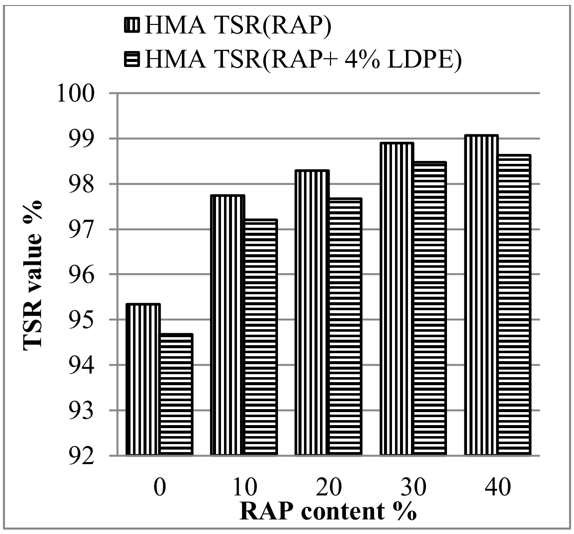

Figure 6. Comparison of TSR

Figure 7. Samples tested for Moisture Susceptibility

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Fatigue Test (ITFT) Results

UTM was used to perform fatigue test, according to the standard EN12697-24. The test was performed in stress controlled condition, according to which stress was kept constant to increase strain within the sample. HMA samples having different RAP contents with and without LDPE (as replacement of OBC) were made for the fatigue test. Samples with 50mm±1mm size with 4 hours conditioning at 25°C were tested under loading of 3500 N. The results of which are given below in Table 4

Since the tests are performed under stress controlled conditions. The increased stiffness of samples will lead to more fatigue life. As RAP contained stiffed material so accordingly fatigue life of samples increases with increasing RAP content in sample. This phenomenon of increased fatigue life due to increased stiffness of mix has been validated in the laboratory by (Copper and Pell, 1974) using stress controlled mode of testing.

For the samples containing both RAP and LDPE content, fatigue life increased but it is slightly less than that of samples containing RAP content only. This can be attributed to decreased bitumen content in sample as LDPE can provide binding properties up to some extent but not that of bitumen.

Table 4. ITFT Results

RAP content (%)	*Average no. of cycles [0% LDPE]*	*Average no. of cycles [4 % LDPE]*
0%	4796	3956
10%	5450	4625
20%	10838	8821
30%	16382	14118
40%	25035	23022

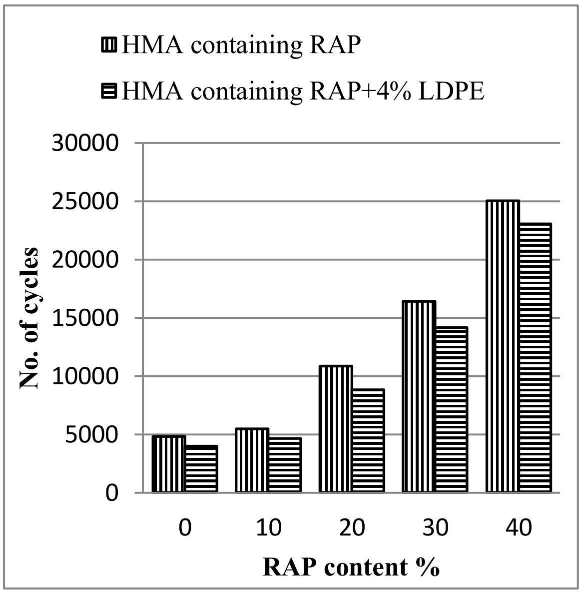

Figure 8. ITFT results

Figure 9. Sample Tested for ITFT

Cost comparison of HMA containing RAP with and without LDPE

Among all other factors affecting cost related to road construction, material cost is the most expensive element. Within which bitumen is specifically the more economically variable material. So the use of RAP up to such level, not affecting the overall performance of pavement, can reduce a portion of virgin aggregate and bitumen utilized in making of pavement. Thereby reducing the overall cost. Similarly, by using LDPE as a replacement of OBC can further reduce cost associated with construction of roads.

In this research cost comparison of control mix, HMA containing RAP and HMA containing RAP and LDPE as replacement of bitumen is done. The comparison is carried out for one kilometer road patch having one lane (3.6 m) and 2 inches' depth. Graphical representation of percentage reduction in material cost is shown in figure 10. According to which saving of 18.7% is achieved by using 20% RAP and saving of 21.8% is achieved by incorporating RAP and LDPE in pavement.

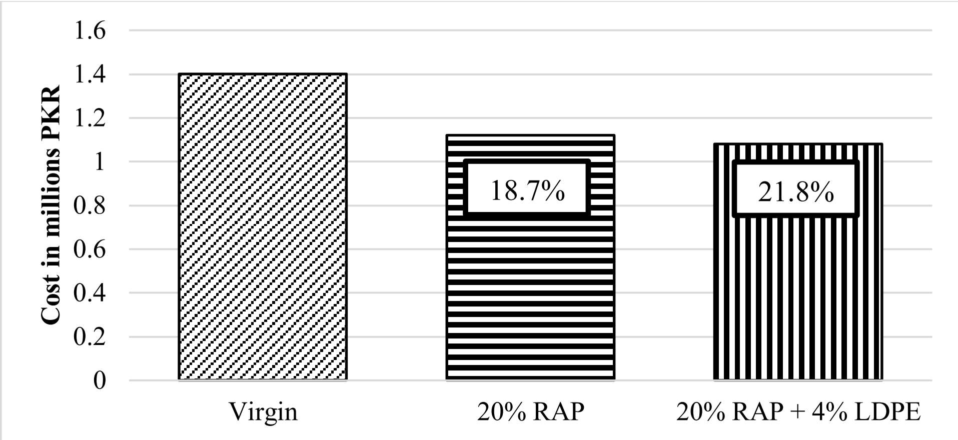

Figure 10. Percentage Decrease in Cost

CONCLUSİONS

The conclusions drawn from the analysis of tests are that: recovered bitumen from the RAP were tested for penetration and ductility and found that by using the 20% of RAP, bitumen still has enough life and bitumen remain within the range of 60/70 grade, so that other performance of pavement like low temperature cracking is not affected. Penetration and ductility tests were performed on the LDPE contents with virgin bitumen limiting the value of LDPE to 4 % of the virgin bitumen which shows that 4% LDPE won't change the binder grade. Results show that increasing RAP contents, with or without LDPE, increases the moisture resistance. While increase in moisture resistance for samples having LDPE also is slightly less as compared to samples having RAP only. Results shows that number of cycles (fatigue life) of the HMA increases with increase in RAP contents in stress controlled condition. Also addition of LDPE slightly reduces the fatigue life of HMA as the virgin bitumen reduces due to its replacement by LDPE. Therefore, after analyzing all the factors 20% of RAP and 4% LDPE as a replacement of virgin bitumen can be used in HMA. Cost comparison of control mix with HMA containing RAP shows that even 20% of RAP and 4 % of LDPE can save up to 21.8%, thus using RAP and LDPE in HMA will not only reduce the cost, but will help us in conserving the natural resources and utilization of the waste materials, making the environment more sustainable.

ACKNOWLEDGEMENTS

The researchers acknowledge that this is only a technical article for experimental investigation of RAP and LDPE combination on moisture damage and fatigue evaluation of HMA. The mixtures' moisture susceptibility was measured by the UTM by performing ITS test and ITFT for fatigue behavior. This research study does not establish a standard, specification, or a regulation.

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