Effect of Rubber Tyre and Plastic Wastes Use in Asphalt Concrete Pavement

F. Onyango, Salim R. Wanjala, M. Ndege, L. Masu

***Abstract*—**Asphalt concrete pavements have a short life cycle, failing mainly due to temperature changes, traffic loading and ageing. Modified asphalt mixtures provide the technology to produce a bituminous binder with improved viscoelastic properties, which remain in balance over a wider temperature range and loading conditions. In this research, 60/70 penetration grade asphalt binder was modified by adding 2, 4, 6, 8 and 10 percent by weight of asphalt binder following the wet process and the mineral aggregate was modified by adding 1, 2, 3, 4 and 5 percent crumb rubber by volume of the mineral aggregate following the dry process. The LDPE modified asphalt binder rheological properties were evaluated. The laboratory results showed an increase in viscosity, softening point and stiffness of the binder. The modified asphalt was then used in preparing asphalt mixtures by Marshall Mix design procedure. The Marshall Stability values for mixes containing 2% crumb rubber and 4% LDPE were found to be 30% higher than the conventional asphalt concrete mix.

***Keywords*—**Crumb rubber, dry process, low-density polyethylene, hot mix asphalt, wet process.

I. Introduction

THE principle roads in South Africa are surfaced with hot-mix asphalt (HMA). In tropical and sub-tropical countries, the performance of HMA has often disappointed under severe climatic conditions with road surfaces sometimes failing within a few months of construction and rarely lasting the design life. The main distress contributing to asphalt pavement failures in South Africa are thermal and fatigue cracking, and permanent deformation. Such distresses are influenced by the rheological properties of the asphalt binder in the asphalt pavement [1]. Fatigue cracking and thermal cracking are associated with lower temperatures and aged binder of high viscosity, while permanent deformation is associated with higher temperatures where its rheology approaches Newtonian behavior [2], [3]. An ideal binder should, therefore display adequate elastic behavior at higher temperatures to resist permanent deformation with a reduced age of ageing and lower viscosity at lower temperatures to prevent fatigue and thermal cracking.

Significant improvements on asphalt quality have been made by the addition of modifiers. Two types of modifications have been proposed to date. These are the use of crumb rubber (CR) and polymer modifiers. Many studies have shown that modifying the asphalt with synthetic and natural polymers increases the viscosity and resistance to moisture damage and reduces the susceptibility to temperature and tendency to flow [1], [4], [5]. Crumb rubber and recycled plastics have been used as binder modifiers, and they have replaced a portion of the mineral aggregates in asphalt concrete mixtures [3], [6]. Polymer modified binders (PMB) contain small percentages of polymers to improve their physical properties. The principal source of raw material for producing crumb rubber modified (CRM) asphalt is scrap tyres [7]. However, concerns over inferior road performance and additional costs of construction have hindered the widespread use of such secondary binders and aggregates in such applications. For these reasons amongst others, research into improving the design and performance of asphalt road surfaces continue to be undertaken [8].

In this study, an attempt has been made to use low-density polyethylene (LDPE) obtained from plastic waste and crumb rubber obtained from worn out vehicle tyres. The aim was to optimize the use of recycled wastes in improving the engineering properties of the asphalt concrete mix. LDPE was incorporated in the bitumen binder using the ‘wet process’ and crumb rubber incorporated in the hot mix asphalt (HMA) using the ‘dry process’.

F. Onyango, M. Ndege, and L. Masu is with the Vaal University of Technology, Vanderbijlpark, South Africa.
Salim R. Wanjala is with the Tshwane University of Technology, Pretoria, South Africa (e-mail: salimrw@tut.ac.za).

II. Materials

A. Asphalt Binder

The asphalt cement used in this investigation was obtained from Sasol South Africa. 60/70 penetration grade asphalt cement was used. This asphalt cement type is widely used in pavement construction in South Africa [8], [9]. The consistency properties tests of the asphalt binder were done and the results given in Table I.

TABLE I
PROPERTIES OF 60/70 BITUMEN

Bitumen Test	Standard Test Method	Bitumen grade 60/70	Standard Specification (SABS 307-1972)
Specific gravity (g/cm^3)	ASTM D70-97	1.03	1.00-1.05
Penetration at 25˚C, (dmm)	ASTM D5-86	68	60-70
Softening point, R&B (˚C)	ASTM D36-70	44.4	46-56
Ductility at 25˚C (cm)	ASTM D113-86	67	50-100
Dynamic Viscosity at 60˚C (Pa.s)	ASTM D4402-91	193.7	120-250

B. Low Density Polyethylene

Discarded plastic grocery bags, dry cleaning bags, and household plastics were used (Fig. 1). Low Density Polyethylene (LDPE) was targeted for use in this experiment to modify the bitumen. Fig. 1 shows a sample of the waste

LDPE bags used in this research. The specific gravity of the low-density polyethylene used was 0.92.

Fig. 1 Low Density Polyethylene

C. Crumb Rubber

Crumb rubber consists of particles ranging in size from 4.75 mm (No. 4 Sieve) to less than 0.075 mm (No. 200 Sieve). Crumb rubber produced by the cracker mill process was supplied by Vidar Rubber Products, Edenvale, South Africa. Crumb rubber passing through 2.36 mm and retained on the 1.18 mm standard sieve size was used for this study with the grading results shown in Table II.

TABLE II
CRUMB RUBBER GRADATION

Sieve size	% Passing	% retained
4.75 mm (No.4)	100.0	0
2.00 mm (No.8)	57.5	42.5
1.18 mm (No.16)	48.0	52.0
0.60 mm (No. 30)	0.5	99.5

Fig. 2 shows a sample of the crumb rubber used in the research.

Fig. 2 Crumb rubber sample

TABLE III
PHYSICAL PROPERTIES OF AGGREGATES

Properties	**Test Value**	**Specification** [10, pp.3-3]
Crushing value, %	10	Maximum of : 25%: HMA base and surfacings 21%: Open-graded surfacings and SMA
10% Fines Aggregate Crushing value, kN	400	Minimum of: 160 kN: HMA surfacings 210 kN: open-graded surfacings and SMA
Aggregate (Treton) Impact value, %	5.3	Maximum 25%
L.A abrasion, %	10	10 %: very hard aggregate 60%: very soft aggregate
Flakiness Index	23.7 39	HMA surfacings: 19 mm and 13.2 mm aggregate: 25 (grade 1*) or 30 (grade 2*) 9.5 mm and 6.7 mm aggregate: 30 (grade 1*) or 35 (grade 2*)
Fractured faces, %	99	HMA surfacings: >95%
Sand equivalent, %	69.2	Minimum of: 50: total fines fraction 30: natural sand fraction to be mixed with aggregate
Density, g/cm^3		
Coarse aggregates	2.673	
Fine aggregates	2.619	
Water absorption, %		
Coarse aggregates	0.44	Maximum 1%
Fine aggregates	0.7	Maximum 1.5%

D. Mineral Aggregates

The coarse and fine aggregates used for this research was supplied by Afrisam (South Africa). The aggregates supplied and used in this research was crushed stones from dolerite rock for both the coarse aggregates fraction and crusher sand for the fines fraction. The physical properties and gradation of the aggregates used are shown in Tables III and IV respectively. The gradation of the aggregates conforms to the South African Pavement Engineering Manual (SAPEM). The tests were done to South African Standard Test Methods, TMH 1 (superseded by SANS 3001).

TABLE IV
MINERAL AGGREGATE GRADATION

Sieve size (mm)	Specified Grading (SAPEM 2003 pp. 4-26)	Adopted Gradation	Percentage		Mass per 1200g briquette
			Retained	Mass	
13.2	84-96	90	10	10	120
9.5	70-84	76	24	14	168
4.75	45-63	50	50	26	312
2.36	29-47	36	64	14	168
1.18	19-33	26	74	10	120
0.6	13-25	18	82	8	96
0.3	10-18	13	87	5	60
0.15	6-13	10	90	3	36
0.075	4-10	7	93	3	36
<0.075	-	-	100	7	84

III. Procedures and Testing

A. Binder Modification

Asphalt cement was heated in an oven at a temperature of 160°C [1]. The required amount of asphalt was weighed into a steel beaker, then the amount of plastic required to yield the desired plastic to asphalt ratio was added from 2-10% by weight of bitumen [11]. The beaker was placed on a hot plate to maintain a mixing temperature of at least 165°C. The laboratory mixer was placed so that the propeller was about 15 mm above the bottom of the beaker and started. The prepared amount of plastic was added gradually to the beaker while stirring. The mixer was continued for 5-15 minutes until a homogeneous plastic modified binder was obtained [12].

B. Consistency Tests

The consistency tests were carried out on the modified binder to obtain the following values; penetration value in accordance with ASTM D5-6, softening point value in accordance with ASTM D36 test standards, ductility value in accordance with ASTM D113-86 test standards and dynamic viscosity value in accordance with ASTM D4402 test standards. The results are presented in Figs. 4-6.

C. Asphalt Concrete Modification

Crumb rubber of sieve fraction 2.36 mm was used to substitute a fraction of the fine mineral aggregates of similar sieve size (2.36 mm) so that the overall grading was maintained. Proportions of 0%, 1% 2%, 3%, 4% and 5% of crumb rubber by weight of the aggregates were used in the asphalt mix [1]. The crumb rubber was introduced to the aggregate mix and mixed evenly into the aggregate mix for 10 seconds then modified binder was introduced into the mixture and the sample mixed thoroughly for 2 to 3 minutes at a temperature of 135°C. The mixture was then placed into a standard Marshall mould with base and collar attached and compacted using the Marshall compactor according to test method specified in ASTM D1559.

IV. Results and Discussion

A. LDPE Modified Bitumen

It was observed that the penetration value decreased with an increase for plastic in the bitumen as shown in Fig. 4. However, modified bitumen with LDPE content greater than 5% had penetration values falling outside the allowable range of the 60/70 penetration grade bitumen. As expected, the LDPE tends to stiffen the bitumen therefore increasing its consistency. Reference [3] also found out that penetration at 25˚C would generally decrease as LDPE content increases which indicates an improved shear resistance in medium to high temperatures. Higher penetration values indicate greater susceptibility to rutting of the asphalt mix [10]. Regression analysis gives a linear function showing a high correlation between penetration and the LDPE content in the bitumen.

The softening point values increased with an increase in plastic content as shown in Fig. 5. The addition of up to 7% LDPE by weight will still result to an acceptable range of penetration. High softening point values is an indication of improvement in resistance to deformation of the asphalt mix [3], [13].

Ductility decreased with an increase in the plastic content in the bitumen as shown in Fig. 6. The results of all the LDPE modified binders tested were within the specification range of 50-100 cm. This test however, has limited use since it is empirical and conducted only at one temperature (25˚C).

The dynamic viscosity of the bitumen increased with an increase in plastic content as sown in Fig. 7. The dynamic viscosity of the modified binder with up to 6% LDPE is within the specified range. Higher viscosity values are an indication of stability whereas lower values indicate greater susceptibility to rutting of the mix. A linear regression analysis shows a good correlation between the binder viscosity and the LDPE content in the bitumen.

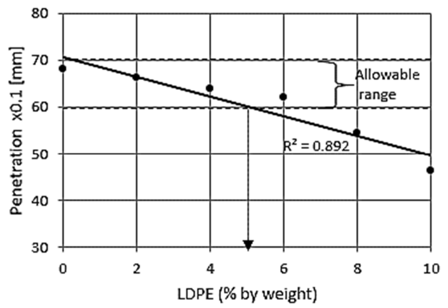

Fig. 4 Influence of LDPE on penetration

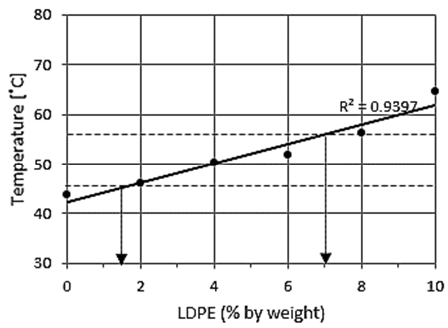

Fig. 5 Influence of LDPE on softening point

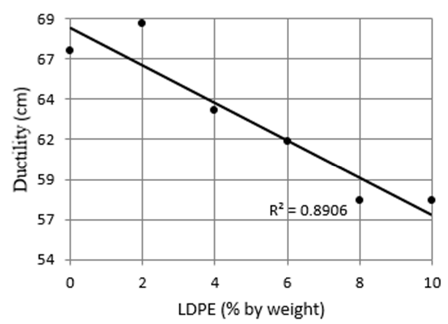

Fig. 6 Influence of LDPE on ductility

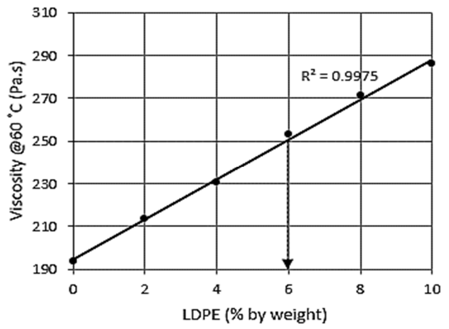

Fig. 7 Influence of LDPE on viscosity

B. Marshall Specimen

A bitumen content giving 4 percent air voids was chosen as the design bitumen content. The optimum binder content was selected as the average binder content for maximum density, maximum stability, 2-4 mm flow and 4% air voids in total mix.

C. Bulk Relative Density

Fig. 8 indicates a decrease in the bulk relative density of the asphalt mix containing 0%, 1% and 2% crumb rubber with increasing percentages of waste LDPE in the mix. This can be attributed to the relatively low density of crumb rubber and waste plastic as compared to the bitumen [14], [15]. The bulk relative density of the mixture remains relatively constant for the mixture with 3% crumb rubber even with an increase in LDPE content. There is an increase in the relative density of the asphalt mixes containing 4% and 5% crumb rubber with an increase in LDPE content.

TABLE V
SUMMARY OF VOLUMETRIC AND MARSHALL DATA FOR 60/70 PENETRATION GRADE BITUMEN

Binder content %	Stability (kN)	Flow (0.25mm)	Bulk Density (g/cm3)	Air voids %	VMA	VFB %
4.5	8.85	3.10	2.452	6.71	16.82	59.74
5.0	9.97	3.26	2.473	5.45	16.21	65.88
5.5	10.61	3.71	2.485	4.62	15.85	70.35
6.0	10.40	3.98	2.489	3.66	15.40	75.79
6.5	8.94	4.22	2.482	4.21	14.75	70.96

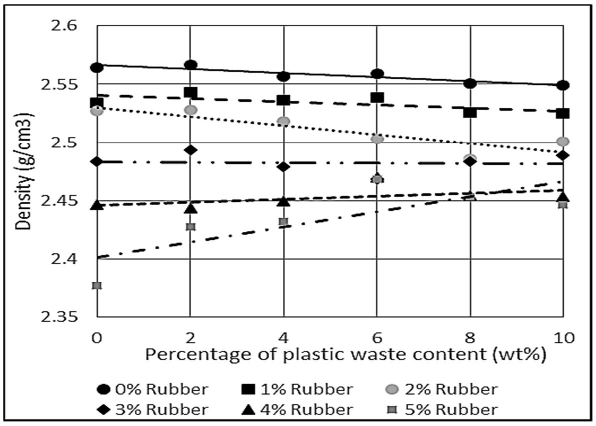

Fig. 8 LDPE/Crumb rubber effect on density of modified HMA

D. Marshall Stability

Figs. 9 and 10 show an increase in the Marshall stability of the compacted briquette with an increase in percentage of polyethylene and rubber content in the mix. However, there is a decrease in the stability values with specimens containing more than 2% crumb rubber. The optimal polyethylene content is at 6% giving a maximum Marshall Stability value of 8.76 kN. The results show that there is impoverishment of quality of mixes with crumb rubber contents higher than 2%. This loss of quality occurred due to a decrease in mix density, an increase in air voids. After reaching, the optimum content there is decline behaviour for both polymers [16]. Reference [17] reported an increase in Marshall Stability values of 10.5 kN, 11.2 kN and 11.85 kN for 3%, 6% and 9% of modifier (LDPE) respectively.

Fig. 9 shows the influence of addition of LDPE and crumb rubber on Marshall Stability. It is can be seen that the LDPE in the HMA mixtures effectively improves the stability of the mixtures irrespective of the crumb rubber content. The mixture with no LDPE exhibits the lowest Marshall stability. For all the mixtures there is an improved stability up to a limit of 2% crumb rubber content beyond which the stability values begin to dip. Cross-linking agents such as sulphur present in the rubber is known to help improve the stability of polymer-bitumen compositions [11]. All the Marshall Stability values at 5% crumb rubber are lower than that of the initial mixtures i.e. 0% crumb rubber. The maximum stability value of 8.86 kN is obtained at 2% crumb rubber and 4% LDPE.

Higher stability values translate to higher HMA pavement performance. Reference [18], [19] observed phase inversion in polymer concentration higher than 6%. Reference [12] found that the optimum result for Marshall Stability, Marshall quotient and flow happened in the binder with 4% HDPE.

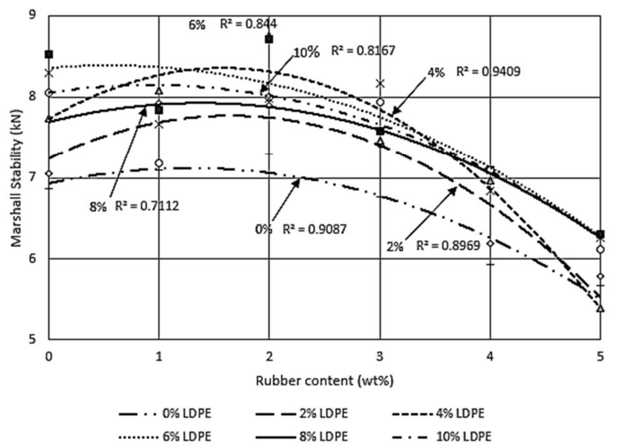

Fig. 9 Influence of crumb rubber content on Marshall stability with variation in LDPE

From Fig. 10 it can be noted that curves of mixtures modified with 1, 2 and 3% crumb rubber shows an improvement in the Marshall stability. However, 4 and 5% crumb rubber content curves exhibit lower stability values than the control sample irrespective of the LDPE content in the mix with 5% having the lowest stability values. It is also important to note that all mixtures containing LDPE shows an increase in Marshall Stability values irrespective of the crumb rubber content.

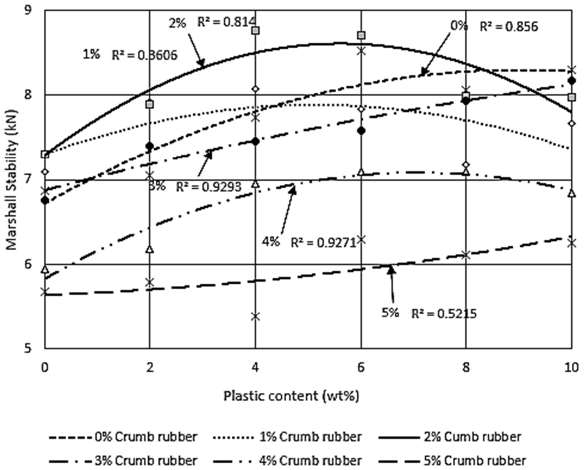

Fig. 10 LDPE content against Marshall stability with variation in crumb rubber contents

E. Marshall Flow

Fig. 11 shows an increase in Marshall Flow with an increase in the LDPE and crumb rubber. The linear regression lines are characterised by high correlation coefficient, R^2 and are almost parallel to each other apart from that of 0% crumb rubber. The higher flow values indicate high flexibility, i.e. the ability of an HMA pavement to adjust to gradual movements in the pavement layers without cracking [12]. The highest flow values are exhibited by 5% crumb rubber and 10% LDPE content. This is an indication that both crumb rubber and waste LDPE increases the flow of the bituminous mix with a potential of reducing low temperature cracking in HMA pavements. Fig. 11 shows that with the increment of waste polyethylene crumb rubber content in the HMA mix the flow values increases. It can be seen that there is a higher increase in flow of the mix with crumb rubber than mixes containing LDPE.

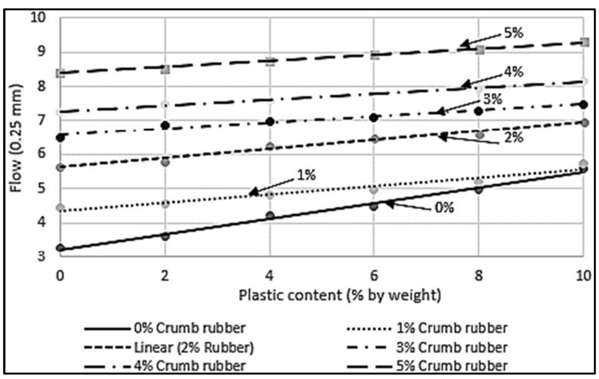

Fig. 11 Influence of crumb rubber and LDPE on Marshall Flow

V. Conclusion

The use of recycled plastic and crumb rubber can therefore be beneficial to the performance of the asphalt concrete pavements as well as provide a means of safe disposal of these non-biodegradable wastes.

References

[1] W. Cao, “Study on properties of recycled tire rubber modified asphalt mixtures using dry process,” Construction and Building Materials, vol. 21(5), 2007, pp. 1011–1015
[2] G. A. Mturi, and J. O'Connell, “Rheological analysis of crumb rubber modified binder,” Pretoria, University of Pretoria, 2011.
[3] A. I. Al-Hadidy, Yi-Qiu and Tan, 2009 “Effect of polyethylene on life of flexible pavements,” Construction and Building Materials, vol. 23(3), pp. 1456-1464.
[4] A. Gawande, G. Zamare, V. C. Renge, S. Tayde, and G. Bharsakale, “An overview on waste plastic utilization in asphalting of roads,” Journal of Engineering Research and Studies, 2012, vol. III(2), pp. 1-5.
[5] L. Flynn, 1993, “Recycled plastic finds home in asphalt binder. Transportation Research Board, 1993, vol. 31(3), pp. 41-47.
[6] Y. Huang, R. N. Bird, and O. Heidrich, “A review of the use of recycled solid waste materials in asphalt pavements,” Resources, Conservation and Recycling, 2007, vol. 52(1), pp. 58-73.
[7] S. Liu, W. Cao, J. Fang, and S. Shang, “Variance analysis and performance evaluation of different crumb rubber modified (CRM) asphalt,” Construction and Building Materials, 2009, pp. 2701-2708.
[8] Department for International Development, “Overseas Road Note 19: A guide to the design of hot mix asphalt in tropical and sub-tropical countries,” Berkshire, UK: TRL Limited, 2002.
[9] SANRAL, “South African Pavement Engineering Manual,” 1 ed. South Africa: South African National Roads Agency Ltd, 2013.
[10] CSIR & SABITA, 2001, “Interim Guidelines for the design of Hot-mix Asphalt in South Africa, 2001. Available at: http://www.asphaltacademy.co.za/pubart.php (Accessed September 2012).
[11] Z. N. Kalantar, M. R. Karim, and A. Mahrez, “A review of using waste and virgin polymer in pavement,” Construction and Building Materials, 2012, vol. 33, pp. 55-62.
[12] S. Hinislioglu, and E. Agar, “Use of waste high density polyethylene as bitumen modifier in asphalt concrete mix,” Materials Letters, 2004, vol. 58, pp. 267-271.
[13] L.P. Fontes, G. Triches, J.C. Pais and P.A. Pereira, “Evaluating permanent deformation in asphalt rubber mixtures,” Construction and Building Materials, 2010, vol. 24, pp. 1193-1200.
[14] R. Siddique, and T. R. Naik, “Properties of concrete containing scrap-tire rubber-an overview,” Waste Management, 2004, vol. 24(6), pp. 563-569.
[15] E. Ahmadinia, M. Zargar, M.R. Karim, M Abdelaziz and P Shafigh, “Using waste plastic bottles as additive for stone mastic asphalt,” Materials and Design, 2011, vol. 32(10), pp. 4844-4849.
[16] N. Rahman, M. Ahmeduzzaman, M. A Sobhan, and T. U. Ahmed,” Performance Evaluation of Waste Polyethylene and PVC on Hot Asphalt Mixtures,” American Journal of Civil Engineering and Architecture, 2013, vol. 1(5), pp. 97-102.
[17] S. Rokade, “Use of waste plastic and waste rubber tyres in flexible highway pavements,” International Conference on Future Environment and Energy (IPCBEE), Singapore: IACSIT press, 2012, vol. 28, pp. 105-108.
[18] U. Isacsson, and X. Lu, “Laboratory investigations of polymer modified bitumens,” Journal of the Association of Asphalt Paving Technologists, 1999, vol. 68, pp. 35-63.
[19] X. Lu, and U. Isacsson, “Modification of road bitumens with thermoplastic polymers,” Polymer Testing, 2001, vol. 20(1), pp. 77-86.