Use of Recycled Asphalt Materials for Sustainable Construction and Rehabilitation of Roads

S. M. Mhlongo[1], O. S. Abiola[1]*, J. M. Ndambuki[1], W. K. Kupolati[1]

Abstract**—**The paper examines the use 100% reclaimed asphalt pavement (RAP) for sustainable construction and rehabilitation of roads. The characteristics of the recovered material were examined in accordance with the South African specifications. The recovered aggregates falls within the envelope for continuously graded mix and the recovered binder is 5.3%. The new hot mix asphalt was design with virgin softer bitumen grade 50/70 to act as rejuvenator at 0, 0.3% and 0.6% to RAP. Test such as Marshall test, indirect tensile strength (ITS), fatigue resistance and workability were conducted. The void ratios were higher than specification at 5.3% bitumen while ITS meets the minimum specified for all the percentages of bitumen. Fatigue resistance of the recycled mixtures increases as the bitumen content increases. The performance of 100% RAP in terms of air voids, stability and ITS at 5.9% binder will be a good material for road construction and rehabilitation.

Keywords**—**bitumen, hot mix asphalt, material, reclaimed asphalt pavement

I. Introduction

THE public, industry and governments have become increasingly interested in green design and engineering as approaches towards better environmental quality and sustainable development. Emphasis on materials conservation, re-use and recycling, had encouraged a number of government and highways agencies to commission research and investigations to characterize, and ultimately optimise, the mechanical properties of recycled asphalt materials [1 – 2]. The construction industry has one of the highest impacts on the environment in regards to energy use, material use and waste products. Within the construction industry, infrastructure construction or highway design is one of the largest economic and also material consuming industries in the world. The use of recycled materials in pavements has become an increasingly widespread practice in recent years. The recycling of existing asphalt pavement materials produces new pavement with considerable savings in material, money and energy. Aggregates and binder from old asphalt pavements are still valuable even though these pavements have reached the end of their service life. Reclaimed asphalt pavement (RAP) is one of the most recycled materials in the world. Several authors' state diverse methods for recycling of asphalt pavements such as: hot recycling in plant, hot recycling "in situ", and others [3-5]. In Europe and US, studies have concluded that 80% of the recycled materials is reused in the construction of roads, but regulation are still strict allowing inclusion of RAP in proportions ranging between 5 and 50 % for production of new hot mix asphalt (HMA) mixtures [6]. Recent researches [3], [7], [9], have established that RAP replacement at proportions above 50 % is feasible to produce new HMA mixtures, obtaining satisfactory results in the mechanical properties. This amount is mainly limited by practical issues related to the production of the mixtures in the asphalt plant. In contrast, the study of recycled mixtures with high RAP content is already a reality in other countries which have begun to produce mixtures with 100% RAP [10 – 12]. Experimenting with recycled mixtures in the laboratory, it is feasible to use 100 % RAP with an adequate performance, provided that an adequate control of the production conditions is guaranteed [3], [13], [14], and [9]. However, it is still quite sensitive to the quality of RAP (origin, variability, stocking) and the production conditions (strict control of temperatures). Regarding the influence of the amount of RAP on the performance of the resulting mixture, in general, the rutting resistance and the stiffness of the mixtures increase with an increase in the RAP content and, usually the increase in stiffness reduces the fatigue resistance of the mixture [15]. The stiffness modulus of a recycled mixture depends on the type of aggregate and its gradation, but the most significant factor is the stiffness of the aged binder present in the RAP [15].

Rejuvenator is one of the recycling agents, suitable for either highly oxidized or for mixtures containing a large percentage of RAP's. Rejuvenation of bitumen is replacement of the oils lost during aging process and on the rebalancing of the bitumen compositions so it becomes no longer brittle. Though, rejuvenator is not encourage or even not allowed for recycling in some states in US due to the uncertainty of the rutting properties of recycled mixtures containing a rejuvenator. However, the rejuvenator percentage may be

O. S. Abiola[1] is with the Dept. of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa (corresponding author's phone: +27844483004; e-mail:abiolaos@tut.ac.za).

S. M. Mhlongo is with the Dept. of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa.

J. M. Ndambuki is with the Dept. of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa.

W. K. Kupolati is with the Dept. of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa.

crucial to the properties of the blended aged asphalt. Rejuvenator should be added properly in terms of the properties of the blend so that the properties under low temperature are improved while the properties under high temperature are not adversely affected. In addition, rejuvenators can penetrate the voids of the pavement, filling them and minimizing the binder oxidation. Some commercial rejuvenators or warm mix asphalt (WMA) technologies have been used by other authors in previous asphalt recycling works [16 – 19]. Oliveira et al. [20] made used of used motor oil, the result showed that the 100 % recycled mixture presented a better performance than the conventional mixture. The objective of this study is to examine sustainability of roads with 100 % recycled asphalt materials for construction and rehabilitation.

II. Material And Methods

A. RAP location and Characteristics

The RAP was obtained from Jabulani Selepe road in Bethal, Mpumalanga Province of South Africa. The road was constructed about 20 years ago without major rehabilitation. Test holes of 1m by 2m to a depth of 1m were opened to check for depth and variability in the layers, three layers were found and sampled. The three layers are, sub-base depth of 150 mm, base layer of 150 mm and 30 mm of asphalt concrete. The characteristics of this material were examined in accordance with standard methods of testing road construction materials [21] and American Society for Testing and Materials (ASTM) standards for the following properties:

- Aggregate test (TMH 1)
- Binder content & properties (TMH 1)
- Characteristics of the recovered binder (ASTM D 36)

The reclaimed asphalt was washed with water to remove foreign materials and the sample was put in the oven and the temperature set at 140^0 C to lose the aggregate from the binder. Recycled binder was extracted from the reclaimed asphalt concrete by solvent extraction method. Solvent was used to separate the binder from the aggregates while rotary evaporator was used for binder recovery. The recovered bitumen was characterized through penetration (ASTM D5), viscosity (ASTM D4402) and softening points (ASTM D36), results presented in Table I. The average recovered binder is 5.3 %, very hard bitumen with low softening point. Properties of the recovered aggregates such as: particle distribution, relative density, water absorption and aggregate crushing value were verified. The gradation and the properties of the recovered aggregates are summarized in Tables II and III. The results showed that aggregate crushing value (ACV) was 11.6% which did not exceed a limit of 25%, flakiness index was 24.2% and water absorption of fine and coarse was 0.459% and 0.302% respectively. The data on the properties of the recovered aggregates met the requirement for continuously graded mix specified by TMH 1 as presented in Table III. Although, the dry 10% fine aggregate crushing force was 96.1 kN which was less than the required 160 kN. The materials are still durable and competent to be re-used. The shape of the aggregates was still in an acceptable condition.

TABLE I
Characteristics Of Recovered Binder

Properties	Value
Binder content	5.3%
Viscosity @ 60^0C	0.124
Viscosity @ 135^0C	0.220
Softening point	32.2^0 C
Penetration	38

TABLE II
Gradation Analysis Of The Recovered Aggregate, Used For The Production Of New HMA

Sieve size (mm)	% Passing	Specification (medium continuously Grade mix)
13.2	100	
9.5	95.6	82 – 100
4.75	68.4	54 – 75
2.36	52.4	38 – 57
1.18	41.3	27 – 42
0.600	33.2	18 – 32
0.300	21.4	13 - 23
0.150	14.4	9 – 16
0.075	9.1	4 – 10

Table III
Characteristics Of The Recovered Aggregates And Specification By TMH 1.

Characteristic of recovered aggregate		Value	Specification (TMH 1)	Value
ACV		11.6%	ACV	25%
Flakiness		24.2	Flakiness	30
Water Absorption			Water Absorption	
	>4.75 mm	0.302	>4.75 mm	1%
	<4.75 mm	0.459	<4.75 mm	1.5%
			Asphalt design specification	
			Aggregates	93%
			Binder content	6%
			Filler	1%

B. Recycled Asphalt Mixture Design

The laboratory test was carried out after determining the material composition of the RAP material. The mixture was design for traffic class E3, which is greater than or equal to 3 million and less than 10 million equivalent single axle loads (ESALs). The same aggregate gradation of the reclaimed asphalt was used since it falls within the grading envelop for medium continuously graded asphalt specified in TMH 1. Softer bitumen of 50/70 penetration was used in the new mixture. Three mixtures were studied; the first was produced without additional bitumen i.e. only RAP, the second with 0.3% of 50/70 penetration grade bitumen and third with 0.6% 50/70 bitumen content. RAP samples were heated to a temperature of 1550 C and compacted with 75 blows per face. The properties of the recycled mixtures were examined in terms of relative density (using Rice's method), bulk density, bitumen absorption, volumetric and Indirect Tensile Strength

(ITS) to test if the 100% recycled mixture will meet specification.

III. Results And Discussion

The results of the indirect tensile strength (ITS) and stability tests are presented in Tables IV and V, as well as the mean of the volumetric properties of the tested specimens. The original asphalt material without additional bitumen i.e. 5.3% bitumen had high relative density (2528 kg/m3) and high air void ratio which is above the specification. The air voids at 5.9% bitumen was slightly higher than the maximum value recommended by specification (3 – 6%). The HMA fabricated with 50/70 bitumen, regardless of the percentage of the bitumen added, exhibited a higher ITS, which is higher than the minimum specified (fig. 1). It can be noticed that the relative density and air voids decreases with the increase in binder content. Table IV revealed that as the bitumen content increases, the workability of the mixtures studied increases and invariably has an influence on the volumetric properties of HMA. The result also demonstrates that the fatigue resistance of the recycled mixtures appears to increases as the bitumen content increases while the bearing capacity decreases. The results obtained in the present study have shown that totally recycled pavement mixtures may be used for wearing course. As shown from ITS, fatigue and volumetric results that the use of 100% RAP with addition of some percentage of bitumen is a very promising solution in terms of economic and environmental factors.

TABLE IV
PROPERTIES OF THE NEW HMA

Binder Content (%)	Stability	VTM	VMA	VFB	Flow	ITS (kPa)	Relative Density (kg/m^3)	Fatigue Resistance	Bearing capacity	Workability
5.3	33.0	8.9	19.9	55.3	2.8	3254	2528	0.083	11.8	0.009
5.6	26.6	8.3	19.9	58.2	3.6	2755	2521	0.135	7.4	0.016
5.9	28.9	6.5	20.7	68.6	2.9	2742	2514	0.100	9.5	0.016

TABLE V
BINDER ABSORBED BY AGGREGATES

Binder (%)	5.3	5.6	5.9
Absorbed binder content (%)	0.373	0.644	0.51

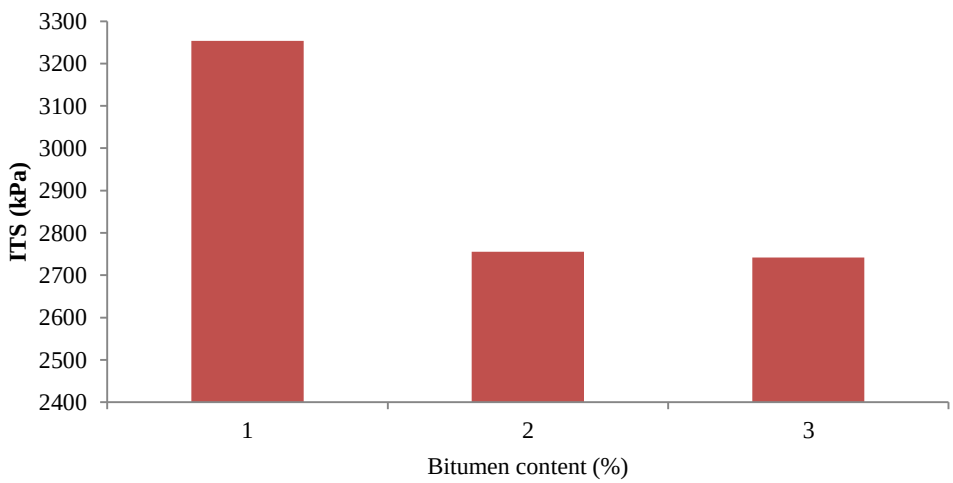

Fig.1 Indirect Tensile Strength for new HMA

IV. Conclusion

This study essentially deals with the need to sustain the roads with recycled asphalt materials, using 100% RAP in HMA mixtures for both construction and maintenance. RAP material was cored and sampled from a rehabilitated pavement, material characterization was conducted and laboratory test were conducted to examine the performance of the new HMA. RAP was rejuvenated with softer bitumen 50/70 grade at 0, 0.3 and 0.6%. The laboratory results showed that the gradation of the recovered aggregates meet the required specification. The properties of the 100% recycled asphalt material evaluated (ITS, workability, fatigue resistance, stability, air voids and relative density showed a better results than the control at 5.9% bitumen. The performance based analysis carried out can be implemented in road construction and rehabilitation.

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