

# Suitability of Reclaimed Asphalt Concrete as a Cold Mix Surfacing Material for Low Volume Roads

Chrispus Sifuma Ndinyo, Zachary Abiero Gariy, Stephen M. Mulei

**Abstract-** Increase in the number of high volume roads constructed to bitumen standards in the past five years in Kenya has led to a strain in the supply of scarce natural resource aggregates. Some of the existing roads have undergone reconstruction which involved removal of top asphalt concrete surfacing layer to accommodate new layers underneath. The disposal of the old asphalt concrete surfacing layer in the open spaces has led to environmental degradation. Lack of sufficient funds has led to low volume roads being left in a deplorable state.

The main objective of the study was to evaluate the suitability of a mix of reclaimed asphalt concrete, virgin aggregates and a cationic emulsion as a surfacing material for the construction of low volume roads. The research involved laboratory investigations and a design process. Reclaimed asphalt concrete, virgin aggregates and a cationic emulsion were evaluated to determine their engineering properties. A combined aggregate gradation for reclaimed asphalt concrete aggregates and virgin aggregates was determined which was used in the determination of the percent emulsion demand for the combined aggregates based on the suggested empirical formula and there after designing an optimal mix according to the modified Marshall mix design method. The optimal gradation envelope from the combined aggregates coupled with emulsion demand that provided a specimen with the desired workability and posing no evidence of surface flushing or bleeding was taken as an ideal mix. The ideal mix provided an optimal stability value of 6900N and a residual binder of 5.2%. The study indicates that the stability values obtained for the designed cold mix were greater than the minimum specified of 3336N for medium traffic surfacing (Asphalt Institute Design Manual, 1994). Cost of producing a unit of reclaimed asphalt concrete cold mix was Kenya shillings 8,445 cheaper than the production costs of conventional asphalt concrete cold mixes in Kenya. The study concludes that reclaimed asphalt concrete cold mix is a suitable surfacing material for the construction of low volume roads. It's therefore recommended as an economical and environmentally friendly surfacing material.

**Key words:** cost, conventional, environmental, modified, optimal.

## I. INTRODUCTION

Roads designed and constructed in the 1970s and 1980s cannot meet present-day traffic needs and require maintenance. An existing aged and distressed road may need more radical upgrading operations (Anastasiyas et al, 2010). Radical upgrading operation of roads is expensive and uses a lot of raw materials. But few people realize that the black tops are completely recyclable and reusing asphalt, as well as other waste materials, to build new roads will save economies great deal of money and precious resources (South Africa Bitumen Association Manual 10, 1992).

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In South Africa, the maintenance of gravel roads places an enormous burden on the roads department's maintenance budget, as almost 29% (2265 km) of the road infrastructure consists of gravel/dirt roads. Roads department officials are constantly pressurized by politicians and residents to provide fully standard "tar" roads; but with current funding levels, this dream can only become a reality over the next 75 years (Henning et al, 2008).

In Kenya, according to Kenya Roads Board (2012), the road network at independence was 45,000 km out of which only 2000 km were paved while the rest was mainly earth road. In order to support the country's development objectives the country embarked on a program of upgrading roads to bitumen standards and improvement of rural roads to gravel standards. As a result, the paved road network was expanded from 2000 km in 1963 to 11,189 km in 2009.

There has been some improvement in the road network condition for the classified roads which is currently estimated at 17% good, 51% fair and 31% poor in condition. However, majority of the paved roads have undergone deterioration and require maintenance and reconstruction. Many of these roads have developed huge potholes, worn out shoulders, clogged drainage and many have become impassable.

It has been recognized that a good quality road infrastructure attract socio-economic development than the bad road condition (Umoren et al, 2001). It is from this angle that the Government of Kenya in the past five years has embarked on a program of rehabilitating the existing road network to motorable conditions. The methods used in the rehabilitation of these roads involve removal of top surfacing material and replacing it with fresh materials. One major maintenance activity is milling of the asphalt layer. The milling activity is necessary because of the many overlays that have been placed in the past to correct surface roughness. Currently, milled material is being used selectively on few projects to blend fill material, otherwise this material is considered as waste, despite finding applications in surfacing drive ways and covering earth roads to control dust.

In the period from August 1987 to August 1988, approximately 1.3 million square meters of asphalt surface area was milled in Riyadh, Saudi Arabia. It is expected that milling operations will increase to approximately two million square meters. Assuming an average density of two tonnes of five centimeters depth, the mass of milled material annually exceed two hundred tonnes. This is only the product of milling streets in Riyadh. Other milling operations have been carried out on major highways. For the municipality of Riyadh, disposing of this material has been found to be very expensive, because of hauling this waste material to distant locations (Basam et al, 1989).

The reconstruction of Kenyan roads in the past five years has seen over five hundred thousand cubic meters of milled material gone to waste. In Kenya the concept of clean production has not been widely embraced particularly in the road subsector. The concept of recycling asphalt concrete is documented as far back as 1915, though it did not get prominence till the oil embargo of the 1970s (Kennedy et al, 1987). Decreasing supply of aggregates, growing concern over waste disposal, and the rising cost of bitumen have resulted in greater need for use of recycling technologies.

### 1.2. Asphalt Recycling

Asphalt recycling is the re-use, usually after some processing, of a material that has already served its first intended purpose. Asphalt binder can be re-melted and re-used several times, regardless of the original method of construction (Basam et al, 1987). Although asphalt materials lose some engineering properties over the years due to oxidation, volatilization and weathering, these losses tend to be minimal in pavements having less than five percent air voids. In such cases, asphalt binder more than 6mm below the surface retains virtually the same composition as the day it was placed. Asphalt materials seldom wear out, but if they do, restoration techniques are available (Karlsson et al, 2005).

Asphalt concrete can be recycled using hot mix, surface or cold mix recycling methods. Hot mix recycling is a process in which reclaimed asphalt concrete materials are combined with new asphalt, recycling agents and new aggregates, as necessary, in a central plant under high temperatures to produce hot mix paving mixtures.

Surface recycling is a process by which an asphalt concrete material surface is heated in place, scarified, remixed, re-laid and rolled (Kennedy et al, 1992). Asphalt recycling agents may be added to obtain desirable mixture characteristics. When new asphalt hot mixtures are added, the finished product may be used as the final surface. Otherwise, an asphalt surface course should be used (Kandhal et al, 1997).

Cold mix recycling is a process in which reclaimed asphalt concrete and virgin aggregates are combined with recycling agents where necessary in place or at central plant, to produce cold mix base mixtures. The principal advantage of the cold laid surface course is the minimum equipment needed to spread and compact the material over the road way surface. The low cost surfaces serve the same functions as thin hot mix wearing courses. However, they cannot be expected to stand up under heavy traffic for an appreciable period of time. For this reason, they are usually restricted to medium and low volume traffic (Mc Daniel et al, 2000).

### 1.3 Low Volume Roads

The criteria for defining a “low-volume road” vary significantly in various parts of the world. Low volume roads are roads that typically carry less than 200 vehicles per day, including up to 20% commercial vehicles, and often include non-motorized traffic, particularly near populated areas (Southern Africa Development Community Guidelines for Low-Volume Sealed roads, 2003). In Kenya, low volume roads are taken as those of traffic class T5 subclasses and traffic below 250,000 cumulative standard axles (Design Guidelines for low volume sealed roads, 2013). The majority of rural roads and a significant proportion of the main roads in Kenya are low volume roads. Most of these roads are currently un-surfaced and are relatively lightly

trafficked. These low-volume roads are important in that they:

- I. Impact significantly on the livelihoods of the majority of the population of Kenyans who live and work in rural areas where poverty levels are generally very high.
- II. Are central to sustained socio-economic growth and development of Kenya and are a key component of development programmes targeted by donors and governments in which poverty reduction strategies features.

### 1.4 Problem Statement

Increase in the number of high volume roads constructed to bitumen standard in the past five years has resulted in depletion of scarce natural resource aggregates in some parts of the country. Some of the existing roads have undergone reconstruction which involved removal of top asphalt concrete surfacing layer to accommodate new layers underneath. The disposal of old asphalt concrete surfacing layer in the open spaces has led to environmental degradation and increase in costs of construction as a result of carting away the removed material to spoil areas. Low volume roads continue to be in deplorable state as a result of low funding and insufficient supply of natural resource aggregates for surfacing these roads. The substantial length of un-surfaced roads in Kenya have become increasingly difficult to sustain in that such roads impose a logistical, technical and financial burden on the government due to constraints on physical, financial and natural resources; these roads also require the continuous use of non renewable resources (gravel and aggregates), which are being seriously depleted in many parts of the country, in the process, causing serious environmental problems.

The suitability of reclaimed asphalt concrete cold mix material for surfacing of low volume roads means provision of whole-life benefits as this; lowers transport (construction, maintenance and vehicle operational) costs; increase social benefits (more reliable access to schools, clinics, etc) and reduce adverse environmental impacts and health and safety problems while reducing the rate of depletion of natural aggregate resources (Figure 1 and 2).



**Fig 1: Reclaimed asphalt concrete dumped in open spaces**



Fig 2: Depleted quarry in Kisumu County



Fig3: Milling activity



Fig 4: Milled material

## 1.5 Objectives

### 1.5.1 Overall Objective

The overall objective of the study was to assess the suitability of an optimally proportioned blend mix of reclaimed asphalt concrete, virgin aggregates and cationic emulsion as a cold mix road surfacing material for the construction of low volume roads.

### 1.5.2 Specific Objectives

- 1) To evaluate the engineering characteristics of reclaimed asphalt concrete aggregates, virgin aggregates and cationic emulsion.
- 2) To design an optimal asphalt concrete cold mix using reclaimed asphalt concrete aggregates, virgin aggregates and cationic emulsion that meets criteria for use as a surfacing material for the construction of low volume roads.
- 3) To compare production cost of designed optimal reclaimed asphalt concrete cold mix against cost of production of conventional mixes used in the construction of low volume roads in Kenya.

## 1.6 Scope and Limitation

The study was carried out in western Kenya. This region experiences tropical climatic conditions. All materials used for the study were locally sourced save for cationic emulsion which was sourced from a supplier in Nairobi. The modified Marshall Mix design method was followed in the designing of the reclaimed asphalt concrete cold mix. The study was a laboratory study with no field trials. The cost of production of designed reclaimed asphalt concrete cold mix was compared against cost of production of conventional cold mixes in Kenya.

## II. MATERIALS AND METHODS

### 2.1 Materials

The materials that were used in the research were reclaimed asphalt concrete aggregates, virgin aggregates and cationic emulsion.

#### 2.1.1 Reclaimed asphalt concrete aggregates.

Reclaimed asphalt concrete aggregates were harvested through a process of bituminous surfacing removal dubbed “milling” (Figure 3), of the Kisumu-Kericho road project which was undergoing reconstruction. The milled material had been stockpiled along the project road for re-use as fill material (Figure 4). Reclaimed asphalt concrete aggregates were randomly sampled from stock piles along the Kisumu-Kericho road project.

### 2.1.2 Virgin aggregates

Virgin aggregates were sampled from a stock pile at a crusher plant at a local quarry in Kisumu. The aggregates sourced were the crushed predominant igneous type of rocks. Crushed aggregates results from crushing fragments of bedrock or large stones, with all the aggregate particles having fractured faces. In the manufacture of crushed stone, solid ledges of bedrock are broken up in a quarry by blasting and further reduced in size by rock crushers. The crushed product may then be screened to produce desired sizes of aggregates. In the processing of crushed limestone, the rock dust produced in the crushing operation is usually separated from other crushed material of 6mm in diameter. This material may either be used as crushed sand aggregate or processed further to maximum size of 0.6mm in diameter for use as mineral filler in asphalt paving mixtures. The aggregates sampled were the aggregate dust, 6mm and 10mm sizes.

### 2.1.3 Cationic emulsion

A drum full of cationic emulsion for use in the research was obtained from Colas East Africa. The supplied emulsion had a test certificate indicating the specifications for the supplied material which had met the requirement for testing as per procedure set out in ASTM D244 for bituminous emulsions.

## 2.2 Methods

The methods used in the carrying out of the study involved carrying out of laboratory investigations and doing a desk study of literature from suppliers, contractors and the local offices of governmental agencies namely Kenya National Highways Authority (KeNHA) and the National environmental management authority (NEMA). Laboratory tests were carried out to inform the study on the engineering characteristics of reclaimed asphalt concrete aggregates, virgin aggregates and the cationic emulsion.

### 2.2.1 Laboratory tests on aggregates

The suitability of aggregates for use in asphalt construction is determined by evaluating the material in terms of; size and grading, cleanliness, toughness, particle texture, surface texture, absorption and affinity for asphalt. The laboratory tests carried out on the aggregates to evaluate the suitability of both reclaimed asphalt concrete and virgin aggregates on the basis of the above parameters were; the stripping test done according to procedure laid down in ASTM D 1664; aggregate grading done according to procedure in AASHTO T 27;

Los Angeles abrasion test done as per procedure in AASHTO T96; aggregate crushing value and bitumen extraction. The other observation tests carried out were cleanliness test as per ASTM 136 and particle shape and surface texture on aggregates.

**2.2.2 Laboratory tests on cationic emulsion**

To evaluate the suitability of cationic emulsion for use as a binder for cold mix asphalt concrete various tests were required, namely; coating ability and water resistance test, particle charge test and sieve test. Conformity to the above tests was achieved by obtaining test certificates from COLAS EAST AFRICA, the supplier of the Cationic emulsion which indicated conformity of material to specifications as to testing procedures laid down in ASTM D 244. The coating test has a threefold purpose. It is intended to determine the ability of emulsified asphalt to: (1) coat the aggregate thoroughly, (2) withstand mixing action while remaining as a film on the aggregate and (3) resist the washing action of water after the completion of mixing. The Particle charge test is an identification test for rapid and medium setting grades of cationic asphalt emulsions. The Sieve Test is used to determine quantitatively the percent of asphalt cement present in the form of pieces, strings, or relatively large globules.

**2.2.3 Mix design**

An optimal reclaimed asphalt concrete cold mix was designed using the Modified Marshall stability formulation. The process involved proportioning the reclaimed aggregates with virgin aggregates to achieve best gradation and establishing the emulsion demand using the empirical formula thereby designing a cold mix using the modified Marshall method (Asphalt Institute Design Manual, 1994).

**2.2.4 Proportioning the materials**

Both the reclaimed asphalt concrete aggregates and the virgin aggregate were subjected to sieve analysis using AASHTO T 27 sieve analysis for fine and coarse aggregates. Virgin aggregates were blended with the reclaimed aggregates to improve recycled mix properties of stability, durability and workability. The virgin aggregates and the reclaimed aggregates were combined in proportions to meet the specific gradation envelope. The proportioning of RAC and virgin aggregates was achieved by varying the amount of RAC at increments of 10% up to maximum of 60% in the mix. A best gradation that provided a compromise of fines and coarse aggregates was selected. The fines and coarse aggregates have a bearing on emulsion content and stability values. Type1 wearing course, 0/10 mm envelope was used for combined gradation (Roads Design Manual part 111, 1987).

**2.2.5 Percent Emulsion demand for the combined aggregates**

Emulsion demand for the combined aggregates was determined using the empirical formula below.

$$P_c = 0.035a + 0.45 b + 0.15 c \text{ for } 11- 15 \% \text{ passing } 75\mu\text{m (No. 200) sieve} + F$$

Where:

- P<sub>c</sub> = Percent of emulsion asphalt by weight of total mix,
- a = Percent of aggregate retained on the 2.36 mm (No. 8) sieve,
- b = Percent of aggregate passing 2.36 mm (No.8) and retained on 75 μm (No. 200) and
- c = Percent of aggregate passing 75 μm (No. 200)

F = 0 to 2.0 % .Based on absorption of light or heavy aggregate. The formula is based on an average specific gravity of 2.60 to 2.70. In the absence of other data a value of 0.7 to 1.0 should cover most conditions.

**2.2.6 Optimal reclaimed asphalt concrete cold mix Design.**

The modified Marshall Stability method was used to design the cold mix using the proportions of reclaimed asphalt concrete aggregates, virgin aggregates and the calculated emulsion demand for the combined aggregate. The design mixtures were prepared in such a way so as to achieve 3% total water content (percent emulsion water + percent water remaining in RAC + percent mixture water added). Emulsions were incorporated into the mixtures at desired content in 0.5% increments. Mixtures were then compacted with 50 blows per face of the Marshall compacting hammer. The compacted specimens were cured for 72 hours at 40°C. Next, the specimens were tested for bulk specific gravity, stability (40°C), and flow (40°C). The maximum specific gravity was then determined. Finally, at the optimum additive content, specimens were prepared at additional total water content at 0.5% increments. The average void content for each moisture content was then determined. Observations were also made based on workability and mix consistency. The selected emulsion content is the highest emulsion content that provided a specimen with the desired workability with no evidence of surface flushing or bleeding. The optimal gradation envelope from the combined aggregates coupled with emulsion demand that provided a mix with desirable workability and posing no evidence for surface flushing or bleeding was taken as an optimal reclaimed asphalt concrete cold mix.

**2.2.7 Cost computation**

A unit cost of producing a cold mix using reclaimed asphalt concrete and virgin aggregates was determined based on the optimal mix proportions earlier obtained. A desk study of literature on costs of producing asphalt concrete cold mix for the construction of low volume roads was done on literature obtained from local Kenya rural roads authority (KeRRA) offices and local contractors to ascertain unit cost of producing asphalt concrete cold mix using conventional methods.

III. RESULTS

Table 1 and 2 provide the summary of engineering properties of RAC aggregates and virgin aggregates. Figure 5 shows the gradation obtained for 100% RAC aggregate material as sampled from stockpiles in the field, while, Figure 6 shows the combined gradation for 0/10 mm aggregates as obtained in the laboratory.

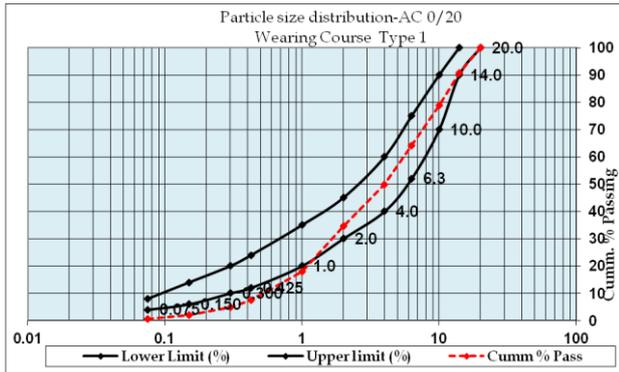
**Table 1: Summary of engineering properties**

Parameter tested	Value obtained	Specification required	Remarks
LAA	28	< 30	good
ACV (%)	15%	10-30%	good
Stripping test %	20	< 25%	good
Gradation	ok	Type 1	good

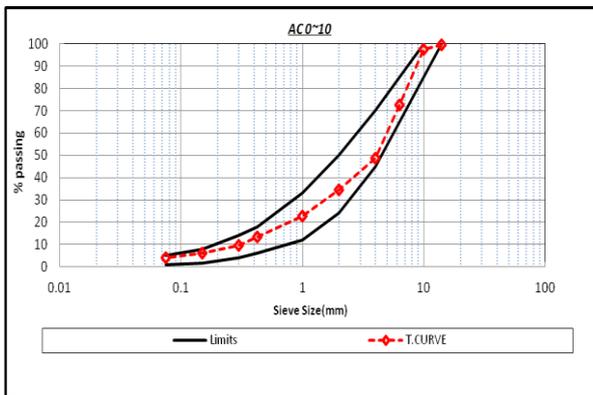


**Table 2: Specific gravity and water absorption for individual sizes**

Aggregate fraction in mix	% in mix	Specific Gravities		
		Bulk	App. Sp.Gr	Water Abs
6~10mm(3/8)"	44.3	2.443	2.583	2.2
0~6mm(Quarry Dust)	31.4	2.598	2.685	1.3
RAP Material>6.3mm	4.3	2.376	2.617	3.9
RAP Material<6.3mm	19.9	2.411	2.606	3.1
Combined Sp. Gr.& Water absorption		2.480	2.620	2.2

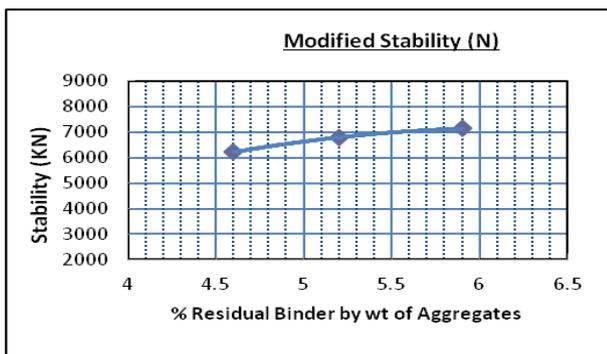


**Fig 5: Gradation envelopes for 100% RAC**

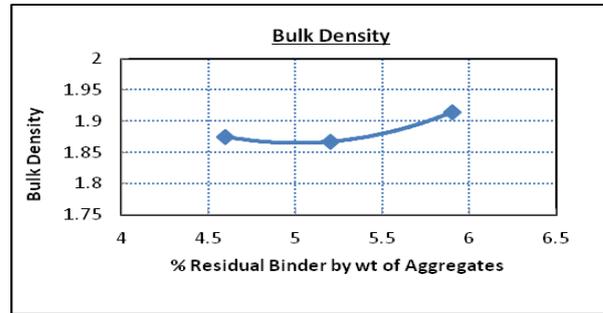


**Fig 6: Combined gradation envelope for 25% RAC and 75 % Virgin Aggregates.**

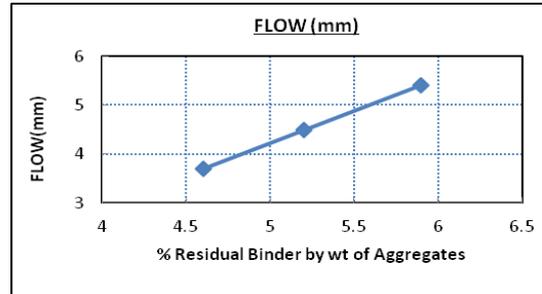
Figures 7, 8, 9, and 10 below, provide the modified Marshall Test results for stability, bulk density, flow and voids after 72 hours of curing.



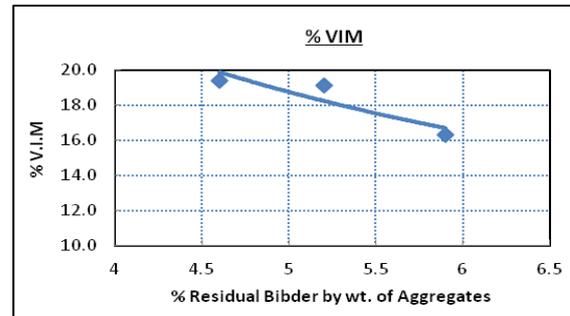
**Fig 7: Stability values for the cold mix**



**Fig 8: Bulk density for the cold mix**



**Fig 9: Flow values for the cold mix**



**Fig10: Voids in the mix values for the cold mix**

From the above Design figures, the optimal Design Emulsion content is 8% (ie.5.2% residual binder content).

Table 3 below provides cost computation comparisons between productions costs of reclaimed asphalt concrete cold mix against production cost of conventional cold mixes used for the construction of low volume roads.

**Table 3: Cost production comparison table for cold mixes**

Mix Description	Item Description	Quantity	Rate	Amount	
Virgin Mix	Aggregates	1.5 tons	1500/=	2250/=	
	Emulsion	130litres	125/=	16,250/=	
	Totals			kshs	18,500/=
	Add 20% handling costs			kshs	3700/=
Total cost of production			kshs	22,200/=	
Cold Mix	Aggregates	0.975T	1500/=	1462.5	
	Emulsion	80 litres	125/=	10,000/=	
	Totals			kshs	11,462.50
	Add 20% handling costs			kshs	2292.5
Total cost of production			kshs	13,755/=	
Cost difference	Cost of virgin-cost of RAC mix		kshs	8,445/m3	



From the above cost comparison Table 3, it can be concluded that the cost of production of cold mix using reclaimed asphalt concrete aggregates is cheaper by Kenya shillings 8,445/= per cubic meter of conventional mixes in the current use. In the reclaimed asphalt concrete cold mix the emulsion content used is 8%, the RAC aggregates used is 25% of mix and 75% of mix is virgin aggregates. Reduced amounts of virgin aggregates and emulsion used in the cold mix results in the total reduction of production cost of reclaimed asphalt concrete cold mix.

#### IV. DISCUSSION

Reclaimed asphalt concrete aggregates provide gradations that are much finer than the virgin mixes and, therefore, must be modified by addition of virgin aggregates in order to be considered for new mixes. This is evident in portions of material coarser than sieve 75 $\mu$ m and finer than sieve 150 $\mu$ m sieve sizes. The gradation of reclaimed asphalt concrete is much coarser than the virgin mixes, especially at the two ends of the gradation curve. The RAC materials depict high coating ability to emulsion and high resistance to stripping. However there is no specific requirements and standard test procedures for designing of cold mixes and hence this research borrowed greatly on a blend of various specifications to meet a higher requirement which sufficed for the lower conditions. The gradation envelope for reclaimed aggregates used was type1 higher stability, as used in the construction of Kisumu-Kericho project. Very high stabilities were obtained after 72 hours of curing (6900N), which are higher than the minimum specified of 3336N for medium traffic surfacing (Asphalt Institute Design Manual, 1994). Higher values of stability are realized when longer periods of curing are provided enabling the specimen to lose the emulsion water and the added water. Notwithstanding, for a cold mix design, the key parameter to be satisfied is durability, a property associated to water-resistance action. In this case it was satisfied using the stripping tests. The average maximum stripping value attained of 20% is acceptable in comparison to the maximum specified value of 25%. The optimal emulsion demand for the designed reclaimed asphalt concrete cold mix is 8% hence lower than the amount of 13% in current use (Guidelines for surfacing roads using labor, 2009). This is a better result. The lower emulsion demand could be as a result of using coarser 0/6 (RAC) aggregates unlike what was applied for in the conventional mixes.

#### 4.3. Conclusions and Recommendations.

##### 4.3.1 Conclusions

Reclaimed asphalt concrete aggregates, as evidenced from summary Table 1 and Table 2, indeed possess engineering properties suitable for use in the surfacing of low volume roads. A 25% saving in coarse aggregate and a 5% reduction in the use of cationic emulsion was attained that greatly reduced the production cost and in return reducing rate of loss of scarce natural resource aggregates. It is evident that 28% of economic saving is attained when reclaimed asphalt concrete is incorporated in the asphalt concrete cold mix manufacture. This saving will result in many gravel roads being surfaced and in return conserve the natural resource gravel material from imminent exhaustion.

##### 4.3.2 Recommendations:

1. The research hereby recommends use of reclaimed asphalt concrete material as a cold mix surfacing material for the construction of low volume roads under the roads 2000 program in Kenya.
2. All milled materials from roads under reconstruction to be stockpiled to allow use for maintenance of low volume roads in the locality of milling to reduce cost and conserve the environment.
3. Government agencies to develop policies and guidelines to allow use of reclaimed asphalt concrete for the construction of low volume roads.
4. Further research is proposed to enable better understanding of material properties and methods of modification and applications.
5. Field tests to confirm the laboratory research in this work need to be carried out.

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Mr. Ndinyo possesses wide experience in the construction industry encompassing highways design and supervision to bitumen standard for multimillion dollar projects in East Africa. He has been specifically been involved in the construction of low volume roads in Kenya and Zanzibar which were funded by the World Bank. The two major programs executed in Kenya and Tanzania was the Roads 2000 program and the Pemba Rural Roads infrastructure development program respectively. These projects were labor based and the aim of the programs was to open up rural areas and hence encourage economic development in under developed areas of the above countries in return reduce poverty levels in accordance to the millennium development goals. The design and execution of these projects under the supervision of internationally respected senior engineers from Kenya, South Africa and Norway, has enabled the author attain much experience in handling bituminous products and in return develop need for greater understanding as to the working of various bituminous materials with an aim of contributing research knowledge in the field of civil engineering and bituminous materials in particular.

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