

## SUITABILITY OF A MIX OF RECLAIMED ASPHALT CONCRETE, VIRGIN AGGREGATES AND A CATIONIC EMULSION AS A COLD MIX SURFACING MATERIAL FOR LOW VOLUME ROADS

**C. S. Ndinyo, A. Gariy and S. M. Mulei**

*Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya*

*E-mail:csndinyo@yahoo.com*

### **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 to evaluate the engineering properties of reclaimed asphalt concrete, virgin aggregates and a cationic emulsion and there after designing an optimal mix. Cost comparison between the production costs of an optimal mix against costs of producing conventional mixes was done to assess the savings obtained when the optimal cold mix was used. A mix proportion that provided an average maximum Marshall Stability value of 4500N and flow value of 3mm was taken as an optimal mix. The results of the study indicate that the stability values obtained for the optimal mix were greater than the minimum specified of 3300N as per Road Note 19 for low volume roads. Production costs of reclaimed asphalt concrete cold mix were found to be cheaper than the conventional mixes. The study concludes that reclaimed asphalt concrete cold mix is a suitable surfacing material for low volume roads. It's therefore recommended as an economical and environmentally friendly surfacing material.

**Key words:** Reclaimed asphalt concrete, optimal mix, cationic emulsion, cold mix surfacing material, low volume roads

### **1.0 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 (Anastasias *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). 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.*, 1998). 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. These three recycling methods are; hot mix recycling, surface recycling and cold mix recycling.

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. There exist preliminary constituent proportioning scheme for hot recycled mix design following the viscosity mixing rule (Aravind *et al.*, 2009). 20-50% of old asphalt concrete is used for recycling activity and use of higher percentage of RAC in recycled mix is generally not encouraged (Flynn *et al.*, 1992).

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.*, 1998). 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, 2003). In Kenya, low volume roads are taken as those of traffic class T5 sub-classes 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.

## 2.0 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).



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



*Figure 2: Depleted quarry in Kisumu County*

### **3.0 Objectives**

#### **3.1 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.

#### **3.2 Specific Objectives**

Specific objectives of the study were to evaluate the engineering characteristics of reclaimed asphalt concrete, virgin aggregates and cationic emulsion; design an optimal asphalt concrete cold mix using reclaimed asphalt concrete, virgin aggregates and cationic emulsion that meets criteria for use as a surfacing material for the construction of low volume roads and 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.

#### **3.3 Scope and Limitation**

The study was carried out in western Kenya. This region experiences tropical climatic conditions. All materials sampled for the study were from the local sources 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.

### **4.0 Materials and Methods**

#### **4.1 Materials**

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

##### **4.1.1 Reclaimed Asphalt Concrete**

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

##### **4.1.2 Virgin Aggregates**

Virgin aggregates were sampled from a stock pile at a crusher plant at a local quarry in Kisumu. The aggregates source was the crushed predominant igneous type of rocks. Crushed stone 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 of sieve sizes 0/6 mm, 6/10mm and 10/14 mm.

##### **4.1.3 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.



*Figure 3: Milling activities on Kisumu – Kericho road project*



*Figure 4: Reclaimed Asphalt Concrete stock piled along Kisumu-Kericho road project*

## **4.2 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 which included 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, virgin aggregates and the cationic emulsion.

### **4.2.1 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 included: 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.

### **4.2.2 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 resistant, 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 coat the aggregate thoroughly, withstand mixing action while remaining as a film on the aggregate and 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. While the Sieve Test is used to determine quantitatively the percent of asphalt cement present in the form of pieces, strings, or relatively large globules.

#### **4.2.3 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, 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 basic proportioning formula given as:

$P = Aa + Bb + Cc$ . 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. Type 2 wearing course, 0/14mm envelope was used for combined gradation (Roads Design Manual part 111, 1987).

#### **4.2.5 Percent Emulsion Demand for the Combined Aggregates**

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

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

Where:

$P_c$  = 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  $\mu$ m (No. 200) and

$c$  = Percent of aggregate passing 75  $\mu$ m (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.

#### **4.2.6 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, mix design as stipulated in the modified Marshall procedure was followed. 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 6 hours at 60°C. .Next, the specimens were tested for bulk specific gravity, stability (60°C), and flow (60°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. The recommended mix design parameters are minimum and maximum design air voids of 9 and 14%, respectively. 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.

#### **4.2.7 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.

### 5.0 Results

Figure 5 shows the gradation obtained for 100% RAC material as sampled from stockpiles in the field while Figure 6 shows the combined gradation for reclaimed and virgin aggregates for 0/14 mm as obtained in the laboratory.

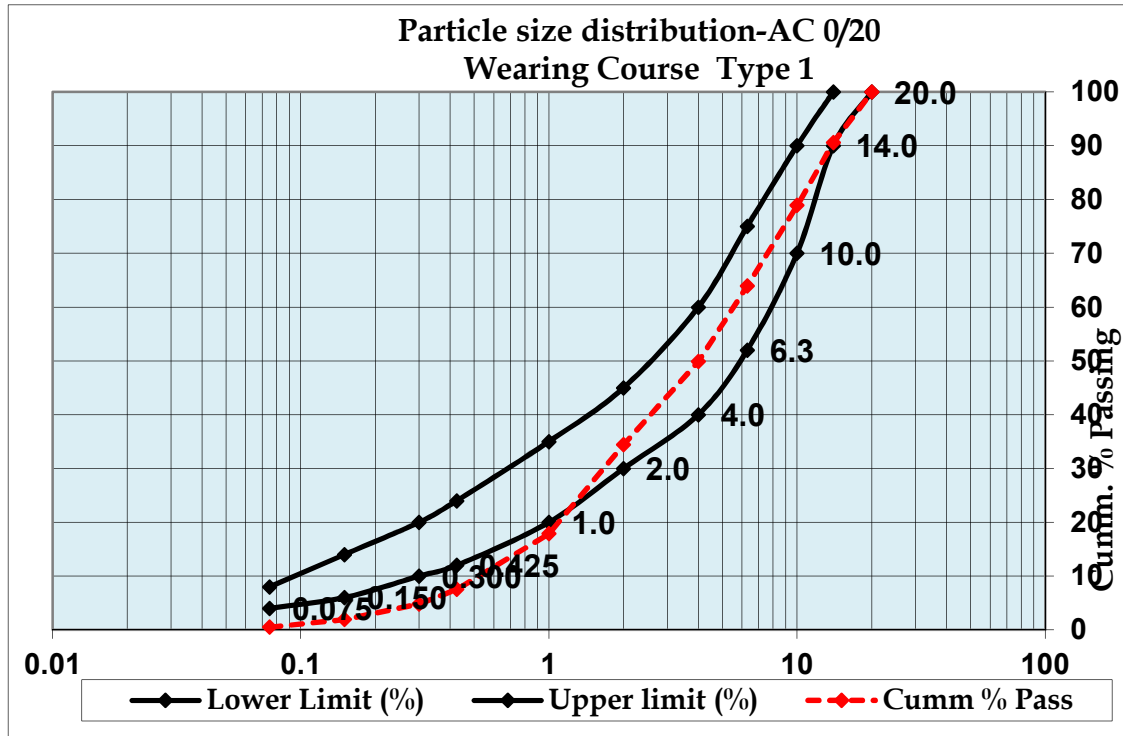


Figure 5: Gradation envelopes for 100% RAC

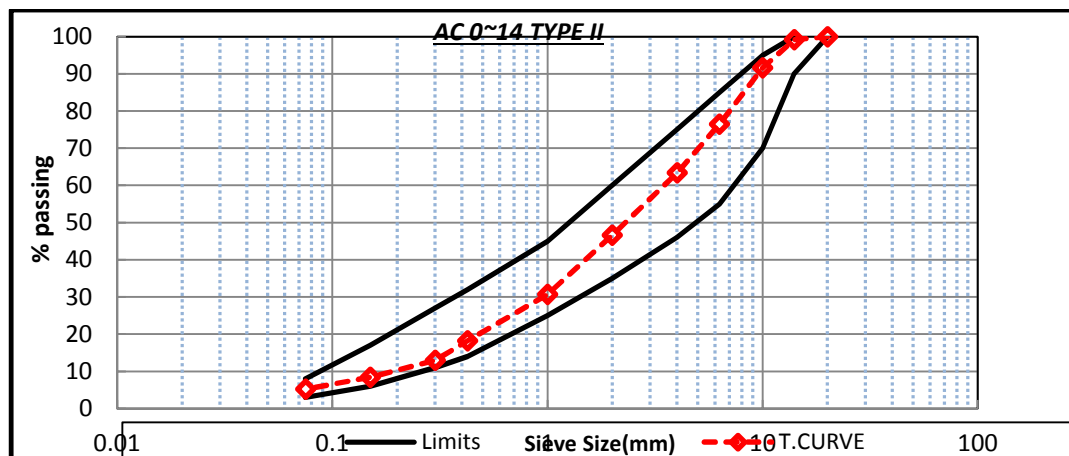


Figure 6: Combined gradation envelope type 2 wearing course 0/14 mm for 35% RAP and 65 % Virgin aggregates

Tables 1, 2, 3 and 4 provides a summary of engineering properties of reclaimed asphalt concrete aggregates and virgin aggregates, engineering properties of designed reclaimed asphalt concrete as obtained using the modified

Marshall procedure, Marshall design criteria and cost comparison computation table for low volume roads respectively.

Table 1: Engineering properties of both reclaimed and virgin aggregates

Parameter tested	Value obtained	Specification required	Remarks
LAA	28	30	good
ACV (%)	15%	10-30%	good
Stripping test %	20	25%	good
Gradation	ok	type 2 envelope	good

Table 2: Marshall Test results Of reclaimed asphalt concrete cold mix

test item	Marshall test results for 6 hours curing at temperatures 60°C							
	6	6.5	7.0	7.5	8.0	8.5	9.0	9.5
Emulsion contents %								
Stability (n)	1450	1550	2450	2750	2800	2400	2200	1900
Flow (mm)	2.6	3.3	3.0	2.95	2.7	3.0	2.15	2.6

Table 3: Marshall design criteria (Asphalt Institute Design Manual, 1994)

marshall method	light traffic		medium traffic		heavy traffic	
	min	max	min	max	min	max
compaction ,number of blows						
each end of specimen	35		50		75	
stability N	2224		3336		6672	
Flow , 0.25 mm	8	20	8	18	8	16
percent air voids	3	5	3	5	3	5



Table 4: Cost production comparison table for cold mixes

Mix description	Item description	Quantity	Rate kshs	Amount kshs
virgin mix	Aggregates	1.5 tons	1500/=	2250/=
	Emulsion	130 liters	125/=	16250/=
	<b>Totals</b>			<b>18500/=</b>
	Add 20% handling costs			3700/=
	Total costs of production			22200.00
Cold mix	Aggregates	0.975 tons	1500/=	1462.50
	Emulsion	80liters	125/=	10,000/=
	Totals			11,462.50
	Add 20% handling costs			2292.50
	<b>Total cost of production</b>			<b>13,755.00</b>
<b>cost difference</b>	cost virgin-cost RAC mix =(22,200-13,755)			8,445/=

From the above tables, it is found that the cost of production of cold mix using reclaimed asphalt concrete 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% and 65% of virgin aggregates is used. This results in a saving in the amount of emulsion and aggregates used for the design of reclaimed asphalt concrete cold mix. The Marshall Test results indicate that the maximum stability values of 2800N and flow values of 2.7mm were attained at 12 hours of curing at a temperature 60°C. The emulsion demand for the mix was 8%.The water content giving the maximum stability was 1%.

## 6.0 Discussion

All the engineering specifications for a low volume road have been satisfied basing on the Asphalt Institute manual, 1994 and Roads Design Manual Part III, 1987. 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. The gradation envelope used for the combined gradation was type 2 wearing course 0/14mm to take care of higher sizes of coarse aggregates in the mix. The stability obtained of 2800N was higher than the value specified of 2224N for light traffic (Asphalt Institute Design Manual, 1994).With increased curing periods this stability will rise to suffice requirements for medium traffic of 3336N. Higher values of stability can be 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 parameters to be satisfied are the workability, consistency and bleeding due to excessive bitumen. In this study the above parameters were satisfied. The emulsion demand for the designed reclaimed asphalt concrete cold mix is 8% hence lower than the amount of 13% in current use. The lower emulsion demand could be as a result of using aggregates from hard rock with low dust production unlike what was applied for in the conventional mixes.

## 7.0 Conclusions and Recommendations

### 7.1 Conclusions

Reclaimed asphalt concrete aggregates as evidenced from summary Table 1 and 2 indeed possesses engineering properties suitable for use in the surfacing of low volume roads. A 35% saving in coarse aggregate was attained that greatly reduced the manufacturing cost and in return reduced rate of loss of scarce natural resource aggregates. It is evident that 38% 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.

## **7.2 Recommendations**

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. All milled materials from roads under reconstruction be stockpiled to allow use for maintenance of low volume roads in the locality of milling to reduce cost and conserve the environment. Government agencies to develop policies and guidelines to allow use of reclaimed asphalt concrete for the construction of low volume roads. Further research is proposed to enable better understanding of material properties and methods of modification and applications.

## **8.0 Acknowledgement**

May I take this opportunity to Engineer Kabubo director SMARTEC for your commitment and prayers during coursework. My staff mates at Norken (I) Ltd, namely; Engineer Protus Murunga, Engineer Idd Noor, Stephen Gakuo, Silas Manyonge, Partson Musuku, Martin Kyambi, Samson Opanga, Evans Karuga, Julliett Khayeli and Susan Omutanyi for their unwavering support. God bless you all.

## References

- Anastasias, M. and Grigorios, P. (2010). A rational approach for optimization of road upgrading. *Canadian journal of civil Engineering*, **37** (11), PP 1462-1470, 10.1139/L10. 7)
- Anderson, D. A. and Kennedy, R. W. (1999). Development of SHRP binder Specification. *The journal of the Association of Asphalt Paving Technologists*, **61**, pp 481-507.
- Aravind, K. (2009). Optimal proportioning for hot recycled mix design under super pave mix design consideration .*Canadian journal of civil engineering*, **36**(9), pp 1470-1477, 10.1139/L096.
- Asphalt Institute Design Manual. (1994) Marshall Design Criteria.
- Aravind, K and Das, A. (2009) A preliminary constituent proportioning for central plant hot mix asphalt. *Journal of materials in Civil Engineering*, **19**(9), pp 740-745 cross Ref.ISI7).
- Flynn, L. (1992). Three states OK more RAP in recycling specs: asphalt recycling and reclaiming. Roads and Bridges (October issue).Scranton Gillette Communications, Inc Arlington Heights, Ill10).
- Kandhal, P. S., and Foo, K. Y. (1997). Designing recycled hot mix asphalt mixtures using super pavetechnology. In progress in Super pave (Superior Performing Asphalt pavements): evaluation and implementation ASTM STP 1322.Edited by R. N. Jester. American Society for Testing and Materials, West Conshocken, Pa.
- Kandhal, P. S., Rao, S. S., Watson, D. E, and Young, B. (1995). Performance of recycled hot mix asphalt mixtures. CAT report NO.95-1, National Center for Asphalt Technology, Auburn University, Auburn, Ala.
- Karlsson, R. and Issacson, V. (2005) Material-related aspects of asphalt recycling-state-of –the-art. *Journal of materials in civil Engineering* **18**(1), pp 81-92 crossRef.ISI
- Kennedy, T. W., Tam, W. O. and Solaimanian, M. (1998). Optimizing use of reclaimed asphalt pavement with the super paves system. *Journal of the Association of Asphalt Paving Technologists*, **67**, pp 311-325a.
- McDaniel, R. Soleymani, H. Anderson, R. M. Turner, P. and Peterson. (2000). Recommended use of reclaimed asphalt Pavement in the super pave mix design method NOHRP Web Document 30.TRB,National Research Council,Washington,D.C.
- Road Design Manual (1987).Part III, Materials and Pavement Design for New Roads, Ministry of Transport and communication, Roads Department, Republic of Kenya.
- South Africa Bitumen Association Manual 10 (1992). Appropriate standards for bituminous surfacing for low volume roads. South Africa Bitumen and Tar Association, Cape Town.
- South Africa Development Community (2003). Guidelines for low –volume sealed Roads, SATCC Technical Unit, Maputo, Mozambique.
- Umoren, V. R. O. Sule and D. D. ENI. (2001). Assessment of some road infrastructural variables in Akwa Ibom State, Nigeria. *Ethiopian Journal of Environmental Studies and Management* Vol.4 No.2, 2011.
- WWW.Kenyaroadsboard.go.ke (2012).Road inventory network, Nairobi, Kenya.