SUITABILITY OF CALCRETE AS A ROAD CONSTRUCTION MATERIAL FOR LOW VOLUME ROADS IN THE ARID AND SEMI-ARID REGIONS: CASE STUDY NORTH-EASTERN KENYA

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ABSTRACT

Gravel materials have to meet the minimum Kenya Road Design Manual (KRDM) Part III specification of grading, plasticity and soaked California Bearing Ratio (CBR) requirements for them to be used for road works in Kenya. Calcrete, which is a gravel material that forms exclusively under arid regions and has different material properties due to its different formation process from the temperate climate soils for which the materials specifications were developed, does not meet these specifications mainly due to high plasticity and low soaked CBR. The main objective of this study was to establish the properties of calcrete materials that relate to their suitability as road construction material. Materials from six sites were subjected to carbonate content test so as to establish if they were actually calcrete and the two material samples (from two of the six sites) with the highest carbonate content selected for further testing. The materials from the two sites were subjected to soil index tests, heavy proctor and CBR tests at different moisture contents under-soaked and unsoaked condition so as to establish the properties of the materials and effect of moisture on their strength. The results obtained indicated that plasticity index results were erratic, while linear shrinkage results were consistent. The CBR value increased by between 100% and 200%, between optimum moisture content (OMC) and dry end moisture content. The study concludes that in the case of calcrete materials, the properties that relate to their suitability as road construction material in the arid regions are linear shrinkage and CBR at the likely in-service moisture content and that a higher degree of compaction be specified in the field and CBR test.

Key words: Properties of calcrete, suitability as construction, arid and semi-arid region

1.0 INTRODUCTION

Road construction materials specifications have been developed empirically on the basis of long-term performance of pavement materials in varying pavement types under different traffic conditions and specific environmental conditions. The application of specifications derived in temperate climates for different road making materials and different traffic loading is inappropriate in Africa, and can lead to unnecessarily expensive construction, or to premature failures (Bulman, 1980). The Kenya Road Design Manual Part III (MOTC, 1981) is a result of successful extrapolation of such specifications achieved by carrying out extensive research programmes, which included systematic evaluation of the characteristics and performance of Kenyan materials and pavements (Serfass *et al*., 1980). In the case of low volume roads it has relaxed the material requirements by allowing higher plasticity for pavement materials and open-textured surfacing or base materials taking into account the traffic volume and climatic conditions but still specifies grading, plasticity and soaked compacted strength for natural gravels (Serfass *et al*., 1980). When these specifications are applied to materials, which due to their different formation processes have different performance-property relationship, they do not comply and are termed as sub-standard or marginal and may not be used. This leads to hauling-in of higher quality materials which results in higher construction cost as the pavement layers (roadbase and sub-base) amount to between 30% to 40% of the construction cost (Cooks *et al*., 2002). One such a soil, which due to different formation process from the temperate climate soils for which the soil mechanics principles have been developed may not meet the specification requirements, is calcrete which occurs in arid and semi-arid regions with mean annual rainfall of less than 550 mm. Extensive research and accumulated experience in the southern African countries where calcrete is regarded as the number one road construction material due to its large occurrence, has shown that the material specification assembled for non-pedocrete materials are far too conservative for pedocretes in terms of grading and Atterberg limits (Klaus, 1992). The accumulated experience showed that the most important criterion for selection of calcrete is the compacted strength at the likely in-service moisture content and that the compacted strength requirement can be relaxed so as to take advantage of the self-stabilising property of calcrete (Klaus, 1992). The above researches have resulted in road material specification for calcrete in the southern African countries like Botswana and Namibia (Klaus, 1992; Overby, 1983). The uniqueness of calcrete with respect to the relevant material properties that should be specified has been recognised in the Fourth Edition of Road Note 31 (Overseas Centre, 1993), which states that in case of calcareous gravels, plasticity requirement can be increased by up to 50% above the normal requirement in the same climate without significant detrimental effect on the performance of an otherwise mechanically stable base. It also states that strict control of grading is less important and deviation from a continuous grading is tolerable in case of calcareous gravels.

Although the existing body of information on calcrete is large, there is still substantial gap particularly with respect to its use in Kenya, as the Kenyan road design manual for pavement materials does not fully cater for the calcrete materials that occur in the arid areas of Kenya since the material is still subjected to the same specification as the non-pedocrete materials. Hence, there was need to study these materials that occur in Kenya so as to determine the relevant engineering properties that need to be specified in determining their suitability as road construction materials in a given road environment. This will enable proper utilisation of such materials to be made, resulting in reduced cost of road construction in the arid region, improved communication and development of such regions.

2.0 MATERIALS AND METHODS

In order to achieve the objectives of the study, the following approach was adopted: Materials from six sites in North-Eastern Kenya were sampled then subjected to carbonate content test, and the two with the highest carbonate content subjected to further tests normally specified in Kenya Road Design Manual so as to determine their suitability as pavement materials and aggregates for sealing. The materials from ElRage and Kargi site were subjected to classification tests, namely, particle size distribution, Atterberg limits, linear shrinkage, field moisture content and specific gravity. Chemical tests, namely chloride content, total sulphate content, pH value and organic matters content were also carried out on the materials. The chloride and sulphate content tests were used in establishing the soluble salt content, while the organic matter content test is used to determine the proportion of deleterious matter. The pH value was used to determine whether the soil is acidic or basic. Aggregate strength tests like aggregate impact value (AIV), aggregate crushing value (ACV), Los Angeles Abrasion (LAA), Sodium Sulphate Soundness (SSS), bitumen affinity and water absorption were also carried out.

The compaction tests were done to determine the optimum moisture content and the maximum dry density for the calcrete and calcrete-sand mixes using the 4.5 kg rammer method so as to carry out the CBR tests. The vibrating hammer compaction tests were carried out for the calcrete and optimum calcrete-sand mixes so as to determine their suitability for dry compaction.

CBR tests for the calcretes and calcrete-sand mixes were prepared at 95% Maximum Dry Density (MDD) of 4.5 kg compaction using dynamic compaction method according to BS1377 test16 and then tested after four days soak and also after one day cure.

3.0 RESULTS AND CONCLUSIONS

3.1 Carbonate Content Test For Calcretes

The results in Table1 show that all the materials contain carbonate content of above 10%, hence they are calcretes (Klaus, 1992). Kargi and ElRage calcretes were selected for further testing due to their high carbonate contents.

Table 1: Carbonate content test results

Material source	Kalacha	ElRage	Kargi	Yooh	Bakaal	Uyam
Carbonate content as CO_2 (%)	28.4	35.0	30.0	28.9	21.6	27.8

3.2 Classification Tests

3.2.1 Analysis of the Classification Test Results

The BS5930: 1981 figures 5 and 31 were used to classify the soils. Using the particle size distribution, plasticity chart and the plastic limit and Kargi calcrete was classified as very silty gravel of high plasticity while ElRage calcrete was classified as well graded silty gravel. Table 2 summarises the grading and plasticity tests conducted for the samples collected and the respective results obtained.

Table 2: Classification tests results for calcretes and sands

Parameter	Number of tests	Kargi calcrete	ElRage calcrete	Kargi sand	Maikona sand
Grading:					
Maximum size		20 mm	50 mm	1.2 mm	2 mm
% Passing 20mm	91	76			
%Passing 2mm		42	43	100	96
% Passing 0.425	3	30	16	17	6
% Passing 0.075		21	13	1	2
Grading Modulus		2.06	2.36	1.78	1.96
Specific Gravity	6	2.67	2.61	2.65	2.64
Plasticity:					
Liquid Limit	7	54	73		
Plastic Limit	7	28	37		
Plasticity index	7	26	36	Non plastic	Non plastic
Linear shrinkage	7	13	14		
Plasticity Modulus		780	560		

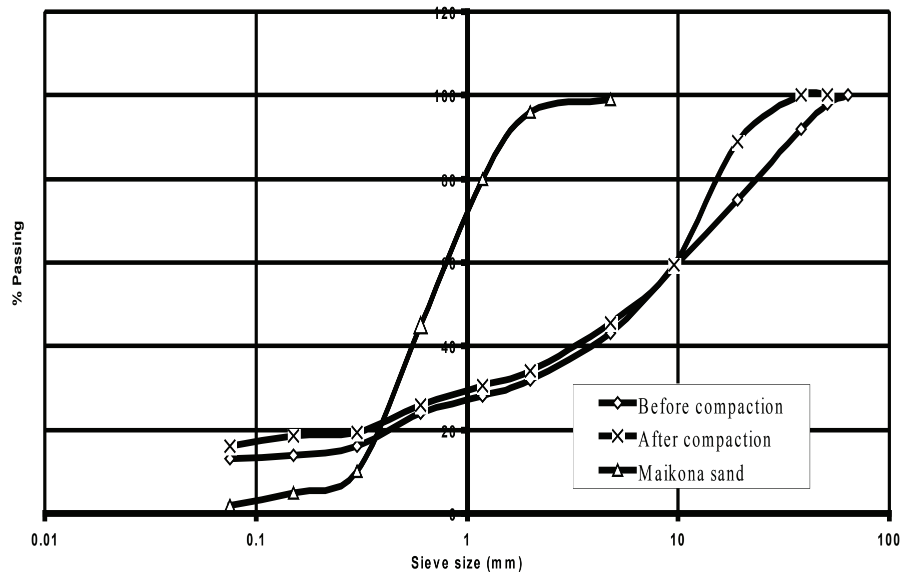

Figure 1: Particle size distribution curves for ElRage calcrete and Maikona sand

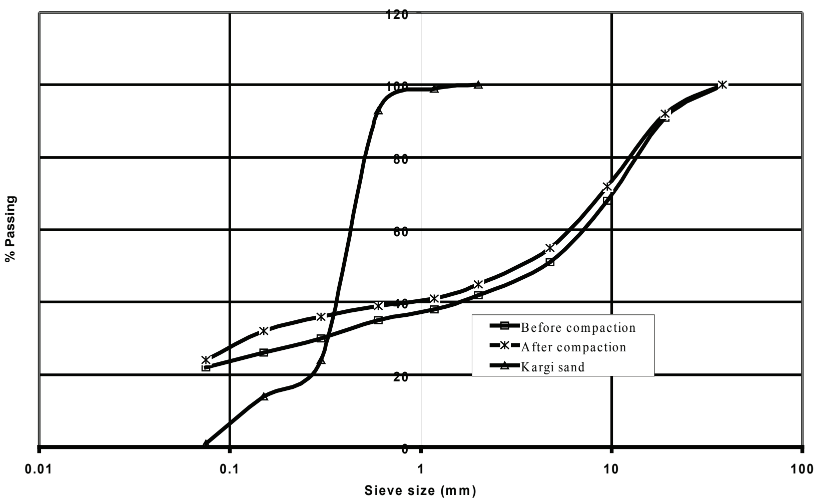

Figure 2: Particle size distribution cerves for Kargi calcrete and Kargi sand

Figures 2 and 3 show the shape particle size distribution curves as, and it can be observed that:

(i) Kargi and ElRage calcretes can be described as fairly well graded, but slightly lacking in the sand fraction.

(ii) Maikona sand is well graded while Kargi sand is uniformly or poorly graded.

(iii) The calcrete materials tested did not undergo considerable change in particle size distribution after compaction.

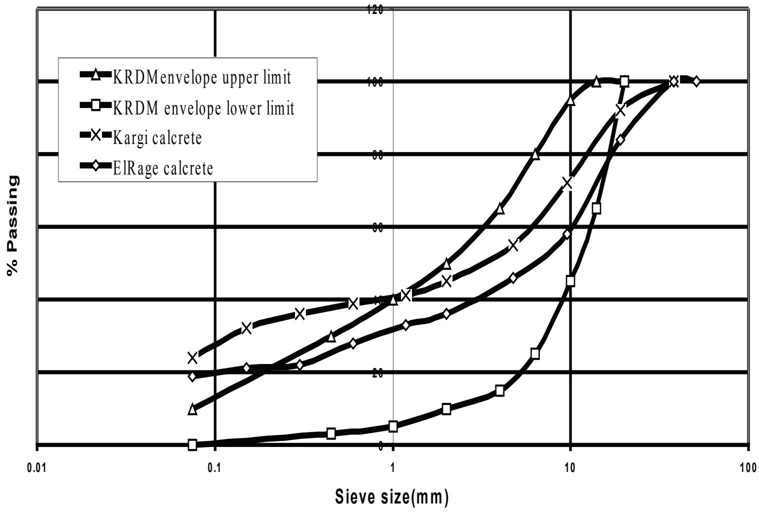

Figure 3: Comparison of calcrete grading curves and the KRDM gravel seal envelope

3.4 Analysis of Plasticity and Linear Shrinkage Test Results

The plasticity and linear shrinkage results were analyzed by establishing the extent of variation of the results obtained for a particular parameter so as to determine the reliability of the mean value as a representative value for that parameter. The analysis is shown in tables 3 and 4 for Kargi calcrete and ElRage calcrete respectively.

Table3: Analysis of Atterberg limits and linear shrinkage results for Kargi calcrete

Property	*Mean Value*	*Standard Deviation*	*Mean Error*	*Range*
Liquid Limit	54	3.5	1.4	12
Plastic Limit	28	3.3	1.3	10
Plasticity Index	26	3.4	1.3	11
Linear Shrinkage	13	0.5	0.2	1

Table 4: Analysis of Atterberg limits and linear shrinkage results for ElRage calcrete

Property	**Mean Value**	**Standard deviation**	**Mean Error**	**Range**
Liquid Limit	73	5.6	2.1	17
Plastic Limit	37	8.1	3.1	24

Plasticity Index	36	10.8	4.1	34
Linear Shrinkage	14	0.9	0.3	2

From the above Tables 3 and 4, the analysis of liquid limit, plastic limit, plasticity index and linear shrinkage results of seven samples for the two calcrete materials shows that:

(i) Atterberg limits results for the two calcrete materials have a wide range, considering that the material tested was from the same trial pit. This makes the plasticity index result unreliable as a parameter for describe the material's plasticity.

(ii) The plasticity index cannot be used as a parameter relating to the calcrete's moisture susceptibility for the following reasons:

(a) The difficulty in determining plastic limit as the material crumbles on remoulding after the thread has passed 3mm diameter without crumbling.

(b) The high liquid limit is attributed at least partly to the porous nature of the very fine calcrete particles, which would raise Atterberg limits without affecting the shrinkage (Director of Roads, 1992).

(c) Calcretes also have shrinkage limit higher than plastic limit, i.e., shrinkage upon drying stops at very high moisture contents (Kenya Polytechnic, 1987).

(iii) Mean linear shrinkage value is a representative value of the values obtained for the samples, as the range is small compared to those for Atterberg limits.

From the above observations, it is concluded that linear shrinkage is a better and accurate measure of moisture susceptibility of calcrete, and that it can be used instead of plasticity index because of the small variation in the value obtained and the peculiar property of the calcrete materials in that they have high shrinkage limit than plastic limit. The linear shrinkage value may then be converted to plasticity index using a factor that has to be determined empirically. An approximate relationship of PI = 2LS is known to exist for most materials (Head, 1984).

3.5 Chemical Tests Results

Table 5 gives the chemical test results for the two calcrete materials.

Table 5: Chemical tests results for calcretes

Test	*Kargi calcrete*	*ElRage calcrete*
Carbonate content as CO_2 (%)	30	35
Chloride content (%)	0.01	0.36
Total sulphate content (%)	0.03	0.48
PH value (%)	8.6	8.4
Organic matter content (%)	0.48	0.59

From Table 5, it is observed that:

(i) The two soils have high carbonate content (Kargi 30% and ElRage 35%), implying that they may have been formed by calcification process.

(ii) The chloride and sulphate contents are high for ElRage calcrete (0.36% and 0.48% respectively) indicating that it has high soluble salt content that may be detrimental even to sealed gravel roads.

(iii) The chloride and sulphate content for Kargi calcrete (0.01% and 0.03% respectively), are too low to have any effect on the gravel base.

(iv) The pH values (Kargi 8.6 and ElRage 8.4), indicate that the two soils are basic confirming the existing information (McKnight *et al*., 2000) that calcretes and other arid region soils are basic.

3.6 Soil Compaction and CBR Tests Results

3.6.1 Compaction and CBR Tests

The soils were subjected to both 4.5 kg rammer (modified AASHTO) and vibrating hammer compaction tests, and the CBR tests carried out on samples moulded at optimum moisture content and 95% MDD of modified AASHTO, and also on samples moulded at low moisture content, which gave highest dry density. The compaction results are presented as CBR results are given in the Figure 4 and 5.

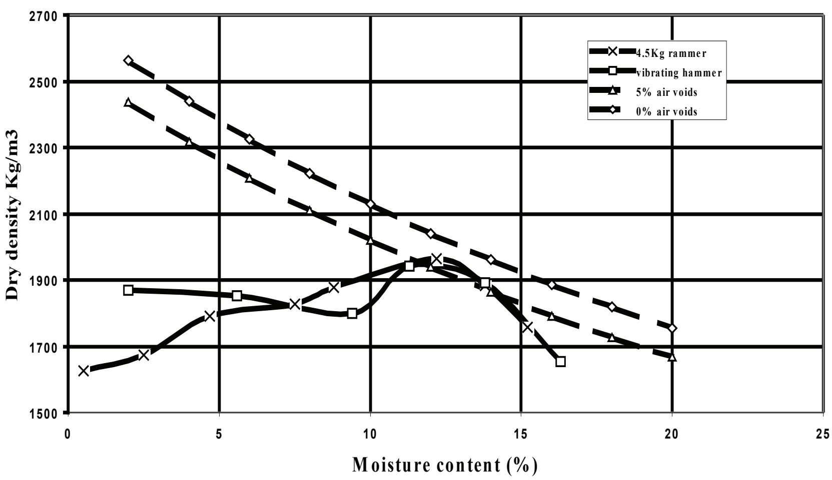

Figure 4: Compaction curves for Kargi calcrete

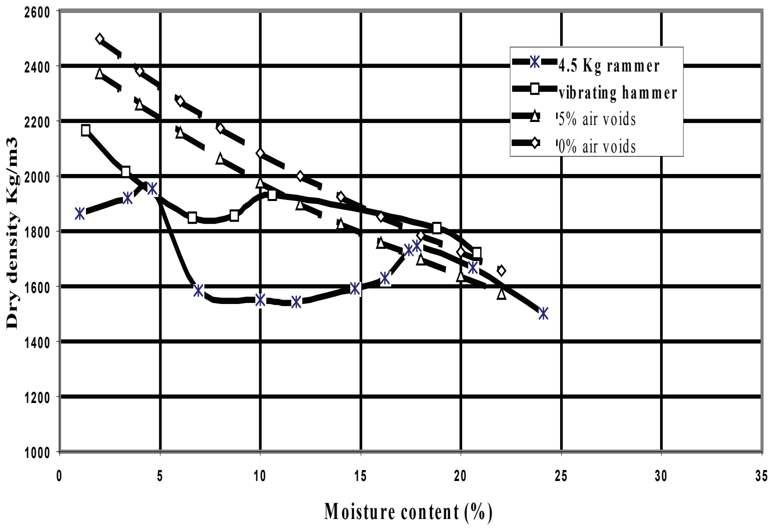

Figure 5: Compaction curves for ElRage calcrete

3.6.2 Analysis of Soil Compaction Test Results

The relationship between the vibrating hammer and 4.5kg rammer compaction methods is that the compactive effort of the vibrating hammer is 4.39 times that of the 4.5 kg rammer (Head, 1984). This indicates that vibrating hammer compaction will result in a higher maximum dry density at lower moisture content than the 4.5 kg rammer test. The compaction curves given in Figure 2 for ElRage calcrete show that the material can be compacted to higher dry density at low moisture content than at OPC and that vibrating hammer test results in higher dry density at the same moisture content than 4.5 kg rammer compaction. In the case of Kargi calcrete, only the vibrating hammer curve shows that the material can be compacted to high dry density at low moisture content These results indicate that ElRage calcrete can be compacted to high dry density at low moisture content, while Kargi calcrete may not be easily compacted to high dry density at low moisture content. From Figures 3 and 4, it is deduced that for ElRage calcrete vibrating equipment will result in higher degree of compaction while for Kargi calcrete, the degree of compaction attained by use of vibrating and non-vibrating equipment are similar. This implies that ElRage calcrete can be compacted to high degree at low moisture content than Kargi calcrete.

3.6.3 Analysis of Compacted Strength Test Results

The CBR test results for calcrete specimens moulded at 95% MDD modified AASHTO and at optimum moisture content and low moisture content both soaked and unsoaked conditions are presented in Figures 6 and 7.

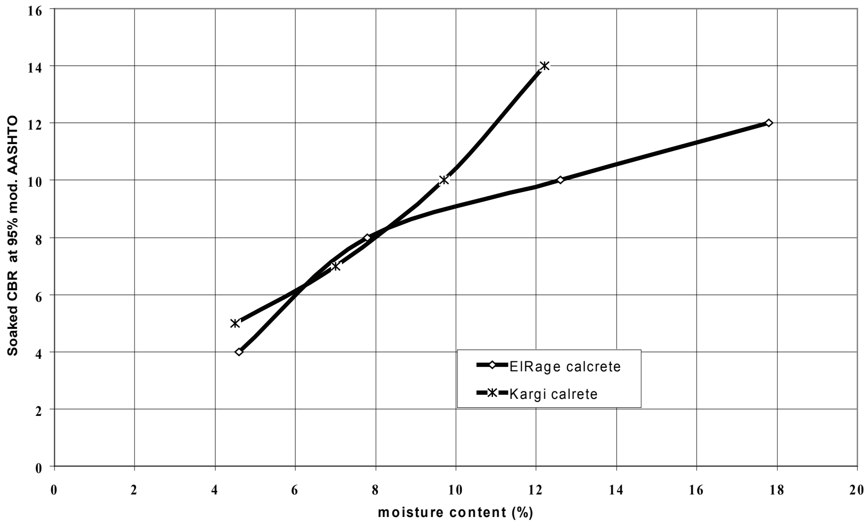

Figure 6: Effect of soaking and moisture on the compacted strength of calcretes

From figures 6 and 7, it is observed that:

(i) The cured-only CBR value of Kargi calcrete increased by about 100% when the moisture is reduced from OMC (12.2%) to 4.5 % while in the case of ElRage calcrete it increased by about 200% when moisture is reduced from

OMC (12.2%) to 4.5%, while in the case of ElRage calcrete, it increased by about 200% when moisture is reduced from OMC (17.8%) to 4.6%, which is the low moisture content which gives highest dry density at the dry end of the compaction curve.

(ii) The soaked CBR value of Kargi calcrete moulded at OMC is 17% of the cured-only CBR value at OMC while that of ElRage calcrete is 12% of its cured-only CBR value.

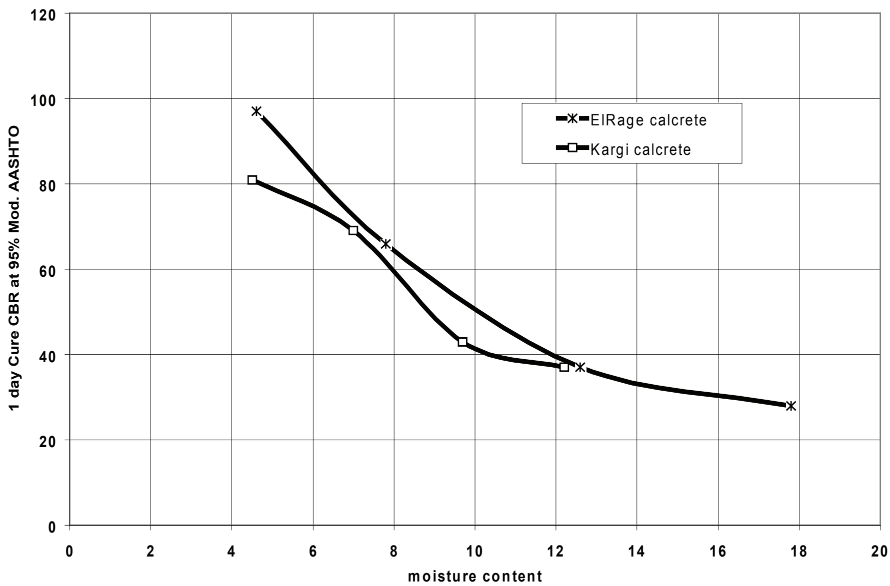

Figure 7: Effect of moisture on compacted strengths of calcretes

This shows that calcrete compacted strength is very susceptible to moisture changes. Therefore, if calcrete is moulded at the expected highest likely in-service moisture content, which is between the dry and optimum moisture contents, it will have higher CBR value. In the case of a sealed pavement in the arid region, this is the most likely situation, as even the optimum moisture content may not be achieved due to the low annual rainfall of about 200 mm. Overby (1982) stated that in Botswana where the annual rainfall was less than 500 mm the tests carried out during the Rural Roads Projects showed that it was unusual even to obtain the optimum moisture content.

Specification of higher compaction level of 100% MDD instead of 95% MDD will also result in higher CBR values as seen in Table 7 where increasing the degree of compaction from 95 percent to 98 percent resulted in increase in strength by between 75% and 85% even under soaked condition. This has been proposed specifically for calcrete in the design approach for low volume sealed roads developed for Southern African Development Community (SADC) region by TRL Ltd (Gourley, 2002). This indicates that if compacted at the likely in-service moisture content and at 100% MDD of modified AASHTO, the materials will have high CBR value, which will make them suitable for use as base material in the arid regions.

3.7 Aggregate Strength Tests Results

Table 8 shows the results of the test carried out to determine strengths of the calcretes.

Table 8: Aggregate strength tests results for calcrete materials

Parameter	*Kargi calcrete*	*ElRage calcrete*
LAA (%) – 'A' grading (%)	38	48
AIV (%) Soaked	29	49
Dry	26	43
ACV (%) Soaked	33	59
Dry	29	31
10%FACT (KN) Soaked		60 20
Dry	110	70
SSS (%)	18	24
Water absorption (%)	5	8
Bitumen affinity: MC3000	Poor	Fair
80/100	Poor	Fair
K1-70	Poor	Fair
A4-60	Good	Good

From the aggregate strength tests results in Table 8, it is observed that:

(i) ACV and AIV results show that the aggregates do not undergo substantial loss of strength with soaking, but 10% FACT results show that the materials undergo substantial loss of strength with soaking (40% for Kargi calcrete and 70% for ElRage calcrete).

(ii) The aggregates are fairly sound

(iii) The aggregates have good affinity for anionic emulsions only.

(iv) In all aspects, Kargi calcrete aggregates are stronger than ElRage calcrete aggregates.

Compared with the aggregate strength requirements proposed in Table 4, the calcrete aggregates tested are fairly durable and strong enough to be used as gravel seal material with anionic emulsion bitumen for very light traffic roads.

4.0 CALCRETE AS A PAVEMENT AND SURFACING MATERIAL

4.1 Calcrete as a Pavement and Surfacing Material for Low Cost Low Volume Sealed Roads

A comparison of the calcrete properties and pavement and surfacing requirements of the Kenya Road Design Manual were made and the results are presented in Table 9.

Table 9: Comparison of calcrete properties and the pavement and surfacing requirements of KRDM (1981) for low standard bitumen roads

Parameter	**Low standard bitumen roads**			**Kargi calcrete**	**ElRage calcrete**
	Subbase	Base	Gravel seal		
CBR at 95% MDD 4 days soak(%)	>25	>50	-	14 (Non-standard for all layers)	12 (Non- after std for all forall layers)
Plasticity Index (%)	<25	<20	<10	26 (Non-standard for all layers)	36 (Non-standard for all layers)
Maximum size (mm)	60	10 -40	20	20mm (Acceptable for all pavement and surfacing)	50mm (Acceptable for subbase)
LAA (%)			<40	38 (suitable)	48(Non-standard)
ACV (%)			<30	29 (suitable)	31(Non-standard)

From Table 9 and Figure 6, it can be observed that the calcrete materials are out of specification in terms of grading, plasticity index and soaked CBR. Kargi calcrete is suitable as surfacing aggregate in terms of LAA and ACV while ElRage calcrete is out of specification even in these aspects. The materials are not suitable as pavement and surfacing materials for low standard bitumen roads according to the KRDM. Calcrete materials did not meet the specification on compacted strength due to the requirement of soaked condition, which may not be attained in the pavement in arid regions under sealed condition. Poor grading and high plasticity may not be considered as serious because it has been found that for calcrete materials, grading and plasticity requirements can be relaxed without affecting their performance in the pavement (TRL, 1993).

4.2 Performance of the Calcrete Materials Against other Low Cost Low - volume Roads Specifications

4.2.1 Pavement Design and Specifications Developed for the Low Cost Low Volume Roads in Kenya for Very Light Traffic

A comparison of calcrete properties and the proposed low cost low volume sealed roads pavement and surfacing material requirements for very light traffic in Kenya (MOTC, 1981) so as to establish if the calcrete materials would have been accepted as road construction material under these specifications, is given in table 10 below.

Table 10: Performance of calcrete materials against the proposed specifications for low volume low cost roads in Kenya

Parameter	*Proposed specifications*		*Kargi calcrete*	*ElRage calcrete*
	Base	*Surfacing*		
Max size (mm)	10-40		20mm (Acceptable)	50mm(Non-standard)
Passing 0.075(%)	<40		21 (Acceptable)	13 (Acceptable)
PI max (%)	25		26 (marginal)	36 (Non-standard)
Min CBR at 95% 4 days soak (%)	25		14 (Non-standard) 37(1 day cure) - suitable	12 (Non-standard) MD 28(1day cure) - suitable
LAA (%)	70	60	38(Acceptable)	48 (Acceptable)
ACV (%)	45	40	29 dry (acceptable) 35 wet (acceptable)	31 dry (acceptable) 59 wet (acceptable)

As base materials, the two materials are out of specification in terms of soaked CBR values, while Kargi calcrete may be acceptable on plasticity and ElRage calcrete is out of specification with respect to plasticity. In the trial section used in developing these specifications the gravel materials for gravel surfacing were sieved so that all material finer than 6 mm was discarded. Hence, the calcrete gravels would need sieving so as to meet this specification. Kargi calcrete aggregates are suitable in terms of strength while ElRage calcrete aggregates are out of specification due to low wet ACV value. The insistence on soaked CBR condition by the Kenyan specifications even under arid climatic conditions makes the calcrete materials unsuitable even under very light traffic condition as pavement materials. However, considering the dry conditions and under sealed pavement, even optimum moisture content may not be attainable in the arid regions. Using the after one-day cure CBR value, the two materials meet the strength requirement for light traffic sealed pavement.

4.2.2 Material and Pavement Design for Sealed Low Traffic Roads in Botswana

A comparison of calcrete properties and the material requirements for sealed low traffic roads in Botswana so as to establish if the calcrete materials would have been accepted as road construction material under these specifications is given in Table 11.

Table 11: Performance of calcrete materials against the proposed specifications for low volume low cost sealed roads in Botswana

Parameter	Proposed specifications			Kargi calcrete	ElRage calcrete
	Subbase	Base	Surfacing		
Max size (mm)	80	63	20	20mm (Acceptable)	50 mm (Non-standard for surfacing)
Grading			Otta seal	Out on fine end of the envelope	Out at both ends of the envelope
Min. GM Passing 0.425 (%)	1.0 83%	1.9		2.6(aceptable) 30 (acceptable)	2.36(acceptable) 16 (Acceptable)
PI max (%)	30	20		26 (Non- standard for base)	36 (Non-standard)
Min. CBR (%) at constructed density.	25 (95% MDD)	40 (98% MDD)		71 (98%MDD) at OMC(Suitable)	49 (98%MDD) at OMC(Suitable)
Soluble salt (%)	0.5	0.3		0.01 (Acceptable)	0.36 (non standard for base)
ACV (%)			<40	35 (Acceptable) wet (non-standard)	31dry (acceptable)59

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Major conclusions arrived at in this research study are as follows:

(i) The materials sampled were all calcrete. However, they have different engineering properties, namely, ElRage calcrete is suitable for low moisture compaction while Kargi calcrete is difficult to compact at low moisture content.

(ii) Linear shrinkage is a more consistent parameter for determining the moisture susceptibility of calcretes.

(iii) Addition of sand to calcrete materials results in increased compacted strength, decreased placidity and improved grading.

(iv) Calcrete aggregate are strong and durable enough for use as gravel seal with anionic emulsion A4-60, but they contain more fines than specified for Otta seal. The gravel materials need to be sieved to remove coarse and fine particles before being used as gravel seal material.

(v) The relevant parameters that need to be specified in determining suitability of calcretes as pavement materials are linear shrinkage and CBR at the likely in-service moisture content compacted to 100% MDD of modified AASHTO if used in sealed pavement.

Generally, it shows that the calcrete materials can be considered for low moisture compaction, which reduces the road construction cost in arid regions where water is scarce.

5.2 Recommendations

Based on the research findings, the following recommendations are made to enable calcrete be used as a gravel material for road construction in arid regions:

(i) A comprehensive study should be conducted to fully understand the performance of calcrete as a pavement material in the arid and semi-arid regions.

(ii) KRDM Part 3 needs to be revised so as to incorporate the findings of studies

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