Gravel Road Material Properties in Rwanda, with Focus on the North and West Provinces

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Abstract: **In spite of large gravel road network in Rwanda, little research has been done on material properties. This culminates into data deficiency, especially for engineering performance and deterioration of gravel roads. In this paper we provide an understanding of the surface materials properties of gravel roads in Rwanda. We establish the functional properties of gravel materials utilised on roads in Rwanda benchmarking on the South African classification system. The analysis is based on gravel road condition data recorded during the visual assessment undertaken in the North and West Province of Rwanda. In our results, the relationship between the grading products, the shrinkage products and the visual condition index (VCI) with associated distresses were assessed and classified into zones from A to E expressing the quality of those materials. Materials were classified into lateritic, volcanic and sandstone groups. The finding indicates that lateritic materials were classified in Zone E (good quality) with good VCI; volcanic gravel in zone B and C and sandstone in Zone B where they can experience corrugation and ravels respectively with poor VCI. The lateritic materials indicate good performance but may have dustiness in dry season. The volcanic gravels were found to be prone to ravelling with low CBR than other materials investigated. It was found also that gravels were having grading out of the suggested grading in TRH14 but showing good grading coefficient. Thus, the monitoring of the performance for local used materials in the construction of gravel road is required to revise or calibrate the existing used specifications based on the performance of available materials.**

Keywords*: *Gravel road, gravel material properties, Rwanda

1. INTRODUCTION

Transport in Rwanda is predominatly road-based. The total road network spans 6655km which 5212km of the classified road network is the unpaved [1]. There are ongoing efforts to improve the existing gravel roads to bitumen, although gravel roads still occupy 78% of the road network and little has been researched on engineering properties especially for material properties. This then culminates into insuffcient data on its engineering performance and deterioration of gravel roads. The deficiencies in data of engineering properties of gravel materials shows poor selection of construction materials and leads to maintenance operation problems and singificantly affects decision making.

The current designs of the wearing course of gravel roads in Rwanda are based on recommendations from French Standards specifications with hardly any information on behaviour of available local gravel materials. This gap then necessitates the need to investigate the properties of unpaved road construction materials to have engineering properties and performance characteristics of the available materials. This will then avail information in the country to assist in the selection and adjustment in the specifications of future designs of surfacing materials of gravel roads.

Thus, the study aimed at establishing functional properties of graveL materials utilised on Rwandan roads focusing on the Northern and Western Provinces and elaborating the correspondance of gravel road condition recorded in visual assessment with South African gravel material performance classification system.

Specifically, study focused on the analysis of grading with parameters like Grading coefficients (Gc), Grading modulus (GM), Dust Ratio (DR), Sand Ratio (SR), Atterberg limits (Liquid, Plastic and Linear shrinkage Limits), California Bearing Ratio (CBR), compaction and the Shrinkage Products (Sp). Those parameters provide an understanding of the surface materials properties of gravel roads in Rwanda.

The geology of North and west provinces of rwanda

The geology of Rwanda generally is made up of sandstones alternating with shales, sometimes intercalated by granitic intrusions [2]. The east of the country is predominately older granites and gneisses. Neogene volcanics are found in the northwestern and the southwestern parts of Rwanda. Young alluvials and lake sediments occur along the rivers and lakes whereas cenozoic to recent volcanic rocks occur in the northwest and west. Some of these volcanics are highly alkaline and are extensions from the Birunga volcanic area of southwestern Uganda [2].

The north and western Provinces are in the highland zones of Rwanda with higher precipitation. The western Province generally lacks road construction materials. The most available materials are basalt in the south, sandstone in the central and the scoria or volcanic gravel in the Northern. The northern Province is largely occupied by volcanic product (i.e. scoria) called lava.

In general such materials are unsuitable for unpaved roads wearing course since they lack sufficient fines and cohesion to bind the grains. In the south-east of the northern Province there are lateritic quarries that are mostly used in gravel road construction.

2. LITERTURE REVIEW

Past studies [3]; [4,5,6,7] attempted to specify requirements for wearing course materials that perform well against traffic and environmental conditions as the main factor damaging gravel road surfaces. Among them with South African conditions, Paige-Green [8] gives the limits based on the grading and plastic behaviour parameters (Table 1) with modifications if the British Standard (BS) test methods is used [7] (Table 2) with the omission of 26.5 mm sieve in grading analysis.

Table 1. Specification of gravel wearing courses for unsealed roads in rural areas [8]

Material properties	**Values**
Maximum size :	37.5
Oversize index (I_o):	5%
Shrinkage Product (S_p):	100-365 (max. 240 preferable)
Grading coefficient (G_c):	16-34
Soaked CBR (at 95%Modified AASHTO compaction, OMC):	>15%
Io: Oversize index (percentage retained on 37.5 mm sieve) S_p = Linear Shrinkage x percentage passing 0.425 mm sieve) G_c = percentage passing 26.5 mm – percentage passing 2 mm) x percentage passing 4.75/100	

The specified material properties can be schematically presented with the related defects.

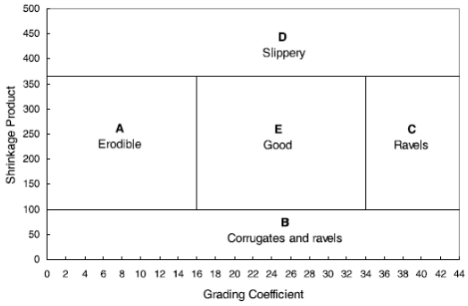

Fig. 1. Relationship between Shrinkage Product, Grading Coefficient and Performance of unpaved wearing course gravels [8]

If the BS test method is used, the limit of the above parameters is adjusted as indicated in Table 2 below.

Table 2: Revised Grading coefficients and Shrinkage products with BS test methods [7]

	SA test methods		**BS test methods**	
	Lower	Upper	Lower	Upper
Grading coefficients (G_c):	16	34	14	30
Shrinkage products (S_p):	100	365	140	400

Visual Condition Assessment

The visual condition index (VCI) is the output of the visual condition analysis. The analysis is performed based on distress data collected through the visual assessment of the pavement surface. The formula proposed in the Technical Recommendation of Highways (TRH22) [9] is used to calculate the visual condition index (VCI).

$$VCI = (a*VCI_p + b*VCI_p^2)^2$$

Equation 1

where: a = 0.02509 ; b = 0.0007 and VCI_p = the preliminary VCI expressed by: $VCI_p = 100\left\{1 - C*\left[\sum_{n=1}^{N} F_n\right]\right\}$

with: $F_n = D_n*E_n*W_n$, n is the visual assessment item number
D_n = Degree rating of defect n, range from 0 to 5
En = Extent rating of defect n, range from 0 to 5
Wn = Weight for defect n (TRH 22)
C = $1/[\sum_{n=1}^{N} F_n(max)]$
Fn (max) = Fn with degree and extent ratings set at maximum

The VCI is established at a standard scale from 0 to 100. The conditions of the pavement assessed are reported using condition categories.

Table 3: Condition categories as per TRH 22 [9]

Description of category	**VCI Range**	**Code**
Very Good	85 ≤ VCI ≤ 100	VG
Good	70 ≤ VCI < 85	G
Fair	50 ≤ VCI < 70	F
Poor	30 ≤ VCI < 50	P
Very Poor	0 ≤ VCI < 30	VP

3. MATERIALS AND METHODS

Rwanda is landlocked with about 26,338km^2 in central part of Africa which lies within latitudes 1°04'- 2°51' S and longitudes 28°45' -31°15' E. It is bordered by Uganda in the North, Burundi in the South, Tanzania in the East and the Democratic Republic of Congo (DRC) in the West. The study was conducted in the northern and western provinces of the country (Fig. 2) and the overall objective was to establish functional properties of gravel utilised during road construction in Rwanda so as to elaborate the correspondance of gravel road condition recorded in visual assessment with South African gravel material performance classification system. This section includes the selection of materials, laboratory tests methods and determination of Visual Condition Index (VCI)

3.1 MATERIALS

Selection of road sections

Preliminary inspection was conducted on eleven (11) unpaved roads in the study area to assess the nature of their surface materials. The aim was to identify roads with gravel materials and different road sections to include in the selection for the study. Only six (6) engineered unpaved road (i.e.: unpaved road with imported layer materials) were selected (Table 4 and Fig.2).

Table 4: Selected gravel roads

ID	**Roads name**	**Length (km)**	**Province**	**Type of materials**
NR17	Nyagahondo -Nyabikenke	39.8	West	Volcanic gravel
NR18	Sashwara-Kabatwa	9.8	West	Volcanic gravel
NR14	Karongi-Gasenyi	61	West	Sandstone
NR7	Shakinyaga - Gashari	66.3	West	Sandstone
NR20	Kiruli-Kirambo	22.1	North	Laterite
DR37	Kirambo-Gahunga	36.54	North	Laterite

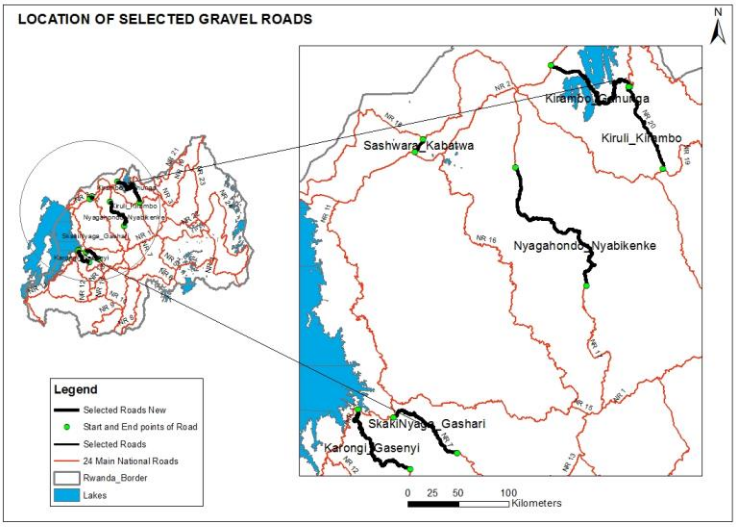

Fig. 2. Location of selected gravel roads

3.2. SAMPLING AND LABORATORY TESTS

In sampling, twelve (12) sections were selected from gravel roads in the North and West Province (2 sections/ road link of 1 km each section). The gravel materials were sampled at the identified sections within 150 mm depth. The samples were excavated from the road pavement by means of hand excavation ensuring that it does not crush excessively the materials and placed in bags to deliver in the laboratory. The field sampling followed guidelines set out in the Material Manual Volume 2 Chapter 4 [10] and TMH5 [11] The laboratory tests such as sieve analysis for the particle size distribution, Atterberg limits including the liquid, plastic and linear shrinkage limit to characterize the fine materials, CBR for strength, the compaction to determine the maximum dry density and optimum moisture content were carried out on sampled materials in accordance with the procedures in BS 1377-2:1990 [12] for classification tests and BS1377-4:1990 for compaction related tests [12]

The grading analyses with their derived parameters are presented for each selected road in section 4 below. The combination of percentage passing through various sieves like 37.5, 28, 4.75, 2, 0.425, 0.075 mm gives the derived parameters. The grading coefficients is given by $G_C = [(P_{26.5}-P_2)*P_{4.75}]/100$, the grading modulus by $GM = (300- P_2– P_{0.425}- P_{0.075})/100$, the sand ratio by $SR= P_{0.075}/ P_2$, the dust ratio given by $DR=P_{0.075}/ P_{0.425}$ and the oversize index by I_o= % retained on 37.5 mm. The analysis based on TRH20 [8], Tompson [13] and Jahren [14] where the recommendable grading coefficient ranges between 16 and 34 with an oversize index of not more than 5%, the dust ratio between 0.4 and 0.6 as well as 0.2 and 0.4 for the sand ratio.

3.3. VISUAL CONDITION INDEX (VCI)

The assessment was processed following the procedure in TMH12 [15]. Equation 1 as proposed in the Technical Recommendation of Highways was used to calculate the visual condition index (VCI). The results from the assessment of the pavement conditions are presented using condition categories (Table 5).

4. RESULTS AND DISCUSSIONS

The results of the visual inspection, the grading analysis, Atterberg limits, compaction related tests and their associated parameters are provided in the tables 5,6,7 and 8 respectively. The interpretation is based on research done by CSRA [8] and Paige-Green [7] for better performance of the gravel wearing courses materials. The performance and classifications are presented and discussed under this section.

4.1. VISUAL CONDITION INDEX (VCI)

Table 5: Results of VCI

Road	Materials	VCI	Category
Shakinyaga- Gashari	Sandstone	49-46	Poor to Fair
Karongi- Gasenyi	Sandstone	18-33	Very Poor
Nyagahondo-Nyabikenke	Scoria	74	Good
Sashwara-Kabatwa	Scoria	73-75	Good
Kiruli-Kirambo	Laterite	78	Good
Kirambo-Gahunga	Laterite	72	Good

The results of combined scores (VCI) of the sections at Shakinyaga-Gashari gravel road are in poor to fair condition due to the stoniness embedded. Higher stoniness, loose materials and poor drainage are the main defects on the road Karongi-Gasenyi. The volcanic gravel roads, Sashwara-Kabatwa and Nyagahondo-Nyabikenke had no severe distress observed however, loose materials at degree 2, dustiness at degree 1 and stoniness embedded at degree 2 were the main defects observed. This is due to the fact that they are newly constructed roads.

4.2. GRADING PROPERTIES

Table 6: Grading properties

	Size (mm)	**37.5**	**28**	**20**	**9.5**	**4.75**	**2**	**1.18**	**0.425**	**0.15**	**0.075**
	TRH14 [16]	100	85-100	70-100		40-60	25-45		15-40		30-7
	Fuller's curve	100	86	73	50	36	23	18	11	6	4
Road section	Section	% passing by mass									
Shakinyaga-Gashari	1	89	79.5	72.5	60.5	54.5	49	47.5	44	23	14.5
	2	92.5	88.5	77	68.5	64	62	61.5	57.5	24.5	14
Karongi- Gasenyi	1	94.5	91	82.5	63	52.5	44	41	35.5	25.5	19
	2	96	91	78.5	58	47	39.5	37	33	24	18.5
Nyagahondo-Nyabikenke	1	98.5	93.5	89	75.5	60.5	43	35	23.5	15	10.5
	2	97	93.5	89	78	66.5	52	45	32.5	21.5	16
Sashwara-Kabatwa	1	94.5	91	85	74	63	48	41	31	22	17

	2	97.5	96	93	81	68	51	45	35	26	20
Kiruli-Kirambo	1	100	99.5	96	84	71	63	61	55	45	41
	2	100	96.5	91	67	48.5	37	35	32	27	24
Kirambo-Gahunga	1	100	96	93	81	65	53	51	47	40	37
	2	100	97	92	75	58	46	44	39	34	31

Table 7: Grading parameters of the selected sections

Road	Section	Sample	GC	GM	Io	SR	DR
Shakinyaga-Gashari	1	1	20	1.89	11	0.29	0.32
		2	19	1.97	11	0.3	0.33
	2	1	19	1.71	9	0.22	0.24
		2	21	1.62	6	0.23	0.25
Karongi-Gasenyi	1	1	33	1.78	0	0.45	0.55
		2	24	2.25	11	0.39	0.51
	2	1	30	2.05	3	0.47	0.59
		2	24	2.13	5	0.43	0.52
Nyagahondo-Nyabikenke	1	1	40	2.34	0	0.26	0.48
		2	44	2.13	3	0.43	0.23
	2	1	42	2.06	2	0.31	0.52
		2	39	1.92	4	0.32	0.49
Sashwara-Kabatwa	1	1	43	1.89	1	0.37	0.57
		2	33	2.21	10	0.34	0.55
	2	1	41	1.94	2	0.42	0.61
		2	42	1.93	3	0.37	0.56
Kiruli-Kirambo	1	1	33	1.52	0	0.64	0.72
		2	31	1.33	0	0.65	0.74
	2	1	34	2.11	0	0.56	0.68
		2	29	2.06	0	0.75	0.84
Kirambo-Gahunga	1	1	29	1.5	0	0.70	0.77
		2	35	1.76	0	0.67	0.81
	2	1	34	1.95	0	0.61	0.75
		2	33	1.71	0	0.74	0.85

Shakinyaga-Gashari

The road is built with sandstone materials. Section one is graveled with brown colored materials while the second section is graveled with white colored sandstones. The particle sizes passing through 0.075 mm sieve vary between 13 and 15% which is within the suggested range between 7 and 30%. The grading of materials on this road presents a remarkable high sand portion far out of the suggested envelope. These may imply a low materials cohesion. Thus, the materials may suffer from ravelling or the surface may have loose gravels. Comparatively to the Fuller's curve (with n=0.5), the grading curves of the material on this road indicate that the materials are poorly graded. The grading coefficients (Gc) vary in the range 19 and 21. In terms of the grading performance they are performing well and are resistant to erosion and ravelling. But the great sand portion over the fines materials represent insufficient fines between particles to increase the cohesion so that they are able to resist to ravelling or loose materials on the surface. The sand ratio (SR) is in the range 0.22 and 0.3. The lowness of this sand ratio results in porous and ravelling surface. The dust ratio (DR) is between 0.24 and 0.33 and the Oversize Index (Io) is between 6 and 11.

Karongi-Gasenyi

The particle sizes passing through 0.075 mm sieve vary between 14 and 24%. The gradings curves are within the grading envelope except the materials at section 1, sample 1 that have a higher sand portion. The grading coefficients (Gc) vary in the range 24 and 33. In terms of the grading performance and comparatively to the performance chart. They are performing well and are resistant to erosion and ravelling. This performance will be justified with the clay content. The sand ratio (SR) is in the range 0.39 and 0.47.

The sand portion is within the range i.e. 0.2 - 0.4. The dust ratio (DR) is between 0.51 and 0.59. The grading modulus is between 1.78 and 2.25. The research by Paige Green [4] shows that the grading moduli equivalent to recommended Gc are roughly 1.5 and 2.6 respectively. The materials present a proportionality of the percentage passing on each sieve. Generally the materials are likely to be well graded.

Nyagahondo-Nyabikenke

Nyagahondo-Nyabikenke gravel road is built with volcanic gravel materials. The percentages of materials passing trough the key sieves i.e. 0.075 mm and 2 mm are in the range 10-17% and 37-55% respectively. The grading coefficients (Gc) vary in the range 39 and 44. Even the grading curves likely to be within the grading envelope, the grading coefficients are out of the recommended range of lower limit 16 and 34 as the upper limit. Having Gc higher than the 34, the materials are prone to ravelling or formation of loose materials in terms of grading performance. The sand ratio (SR) ranges between 0.26 and 0.43. The dust ratio (DR) is between 0.51 and 0.59.

Sashwara-Kabatwa

The gravel road Sashwara-Kabatwa is also built with volcanic gravel materials. Their gradings are like the grading curves of Nyagahondo-Nyabikenke gravel road. With the percentages of materials passing through 0.075 mm and 2 mm sieve in the range 14- 20% and 40-55% respectively. The oversize index (Io) is between 1 and 10 with the maximum size of 37.5 mm. The grading coefficients (Gc) vary in the range 33 and 43.

The Gc is out the recommended range at the upper limit. The materials are prone to ravelling and formation of loose materials. The sand ratio is between 0.34 and 0.42 is much more in the recommended range with dust ratio between 0.55 and 0.61. The dust ratios are closer to the upper limit of 0.6 whereby more than this figure, there is generation of much dust. During the laboratory test, the mica sheets were observed in the sampled materials. The mica reduces the binding properties of the fines and its strength.

Kiruli-Kirambo

The gravel road Kiruli-Kirambo is constructed with lateritic materials (identified visually). The materials on this road have high particle sizes passing through 0.075 mm sieve varying between 21 and 43%. This amount of fines governs the performance of those materials. Higher fine contents imply a higher cohesion of the wearing courses due to the fact that the fines are binders between coarse gravels. With higher fines generate higher dust generation during the dry season and slipperiness in wet period. However, the grading coefficients (Gc) in the range 29 and 34 are within recommendable ranges 16 and 34. In terms of the grading performance, they are performing well and are resistant to erosion and ravelling.

Kirambo-Gahunga

This road is constructed with lateritic materials. Percentage passing through 0.075 mm sieve is between 26 and 40%. Higher amount of fine contents result in higher dust ratio varying between 0.75 and 0.85 and a sand ratio ranging between 0.61 and 0.74. The grading modulus is between 1.5 and 1.95. With higher fines, they may result in higher dust generation during the dry season and slipperiness in wet period. The grading coefficient is between 29 and 35 within the recommended limits as per TRH20 [8]. They are resistant to erosion and ravelling.

4.3. ATTERBERG LIMITS RESULTS

The results of the Atterberg limits (i.e. liquid, plastic and linear shrinkage limits) and the derived parameters such as the plastic index (PI) and the shrinkage product (S_p) that is the product of the linear shrinkage with the percentage passing through 0.425 mm sieve for each section and each samples of the wearing course are presented in Table 8.

The materials reported as NP and SP have been found to have higher sand content with less fines. The study establishes that such materials are difficult roll into threads due to crumbling that inhibits the rolling into threads. Nevertheless, their linear shrinkage is not necessary zero. This is attributed to the traditional methods of carrying out the plasticity test with the portion of materials passing through 0.425 mm sieve. This fraction may mask the plasticity behaviour that can be mobilised by silt and clay fraction i.e. fraction passing through 0.075 mm sieve [17]

Table 8: Results of Atterberg limits

	Shakinyaga-Gashari				Karongi-Gasenyi				Nyagahondo-Nyabikenke			
Section	**1**		**2**		**1**		**2**		**1**		**2**	
Sample	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
LL (%)	22	25	25	27	24	24	28	25	32	33	31	29
PL (%)	NP	NP	NP	NP	NP	NP	18	SP	NP	NP	SP	SP
PI (%)	-	-	-	-	-	-	10	-	-	-	-	-
LS (%)	0	0	0	0	1	3	5	1	0	0	1	3
S_P	0	0	0	0	29	72	159	21	0	0	19	96
Sashwara-Kabatwa					**Kiruli-Kirambo**				**Kirambo-Gahunga**			
Section	**1**		**2**		**1**		**2**		**1**		**2**	
Sample	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
LL (%)	39	33	47	38	36	32	26	36	37	38	28	31
PL (%)	26	24	30	SP	20	19	14	21	19	22	12	15
PI (%)	13	9	17	-	16	13	12	15	18	16	16	16
LS (%)	5	4	6	4	8	6	6	7	7	7	5	7
S_P	168	100	210	140	416	348	176	213	381	273	163	287

The gravel roads Shakinyaga-Gashari and Karongi-Gasenyi with wearing sandstone materials are non plastic with low liquid limit and low shrinkage product according to test results due to low cohesion of the materials. These imply the susceptibility to ravelling and corrugations.

Nyagahondo-Nyabikenke road materials were slighly plastic (SP). They have low plasticity and it was difficult to determine the plasticity limits because the materials were not practicaly plastic. Lateritic materials on Kiruli-Kirambo and Kirambo-Gahunga road have high plasticity.

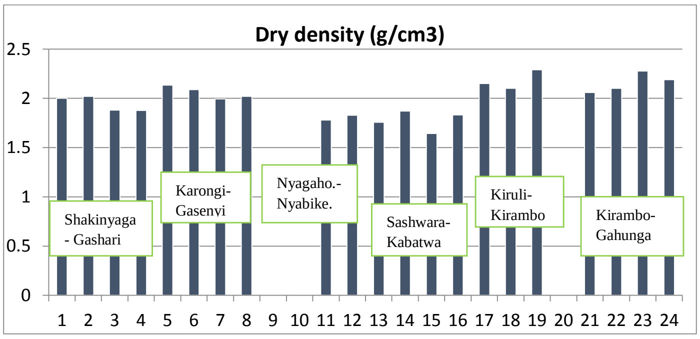

Fig. 3. Dry density at selected gravel roads

4.4. COMPACTION TESTS

The compaction related tests are the compaction tests and the California Bearing Ratio tests. The compaction test aims at determining the dry density and moisture content relationship of a soil compacted at a certain effort. In the laboratory the BS 1377-4:1990: 3.5 was followed. The laboratory tests methods in BS1377-4:1990:7 was followed for the preparation of the sample soil and testing for the CBR. Fig.3 presents the results of density.

The gravel road materials at Shakinyaga-Gashari and Karongi-Gashari roads have relatively a high dry density varying between 1.882 and 2.134 g/cm^3 with optimum moisture content in the range 6.8 and 10.2%. The dry density of volcanic gravel on roads are in the interval between 1.644 and 1.872 g/cm^3 with optimum moisture content between 11 and 16.2%. The lateritic gravel on roads has dry density in the interval between 2.06 and 2.29 g/cm^3 with OMC between 5.9 and 11.8%.

The volcanic gravel roads have relatively lower density than other materials. This should be attributed to its formation process where some voids in particles as cavities that remain unpacked. According to Hobart M. King [18], they are formed when magma containing dissolved gas flows from a volcano. During the eruption the pressure upon the molten rocks emerged from the earth reduces and the dissolved gas starts to escape in the form of bubbles. If the molten rock solidifies before the gas has escaped the bubbles become small rounded or elongated cavities in the rock.

4.5. PERFORMANCE, CLASSIFICATION AND SPECIFICATIONS

The combination of the tests results and the derived parameters defines or exhibits the performance and classify the materials when used on the road. This section classifies the wearing course materials in terms of the performance and presents remedial measures to the possible defects on the selected roads.

4.5.1. GRAVEL CLASSIFICATIONS

The materials are classified as per TRH4 [19], AASTHO and USCS [20]. Those classification systems classify materials from their grading characteristics, their strength in terms of CBR and their Atterberg limits. The classification in TRH4 for the selected roads are from G5 through G8 based essentially on their strengths i.e. CBR as the main feature.

Materials on roads Shakinyaga-Gashari, Karongi-Gasenyi, Nyagahondo-Nyabikenke and Sashwara-Kabatwa with less plasticity behaviour have silty content reducing their cohesiveness while materials on roads Kiruli-Kirambo and Kirambo-Gahunga have clayey soil. The results of classification are presented in Table 9.

Table 9: Classification of gravel materials

						TRH4	**AASHTO**	**USCS**
	Fines	LS	LL	PI	CBR			Symbols
Road	%	%	%	%	%			
Shakinyaga-Gashari	15	0	22	NP	56		A-2-4	GM
	14	0	25	NP	55	G5	A-1-b	GM
	13	0	25	NP	67	G5	A-3	SM
	15	0	27	NP	72	G5	A-3	SM
Karongi-Gasenyi	24	1	24	NP	73		A-1-b	GM
	14	3	24	NP			A-1-b	GM
	20	5	28	10	29	G6	A-2-4	GC
	17	1	25	SP	20	G7	A-1-b	GM
Nyagahondo-Nyabikenke	10	0	32	NP			A-1-b	GW-GM
	11	0	33	NP	25	G7	A-1-b	GW-GM
	15	1	31	SP			A-1-b	GM
	17	3	29	SP	21	G5	A-1-b	GM
Sashwara-Kabatwa	20	5	39	13	16	G7	A-2-6	GC
	14	4	33	9	14	G8	A-2-4	GC
	21	6	47	17	19	G7	A-2-7	GC
	19	4	38	SP	17	G7	A-2-4	GM
Kiruli-Kirambo	38	8	36	16	13	G8	A-6	GC
	43	6	32	13	20	G7	A-6	GC
	21	6	26	12	31	G6	A-2-6	GC
	27	7	36	15	24	G7	A-2-6	GC
Kirambo-Gahunga	40	7	37	18			A-6	GC
	33	7	38	16			A-2-6	GC
	26	5	28	16			A-2-4	GC
	36	7	31	16			A-6	GC

4.5.2. PERFORMANCE ZONES OF GRAVEL WEARING COURSES

The relationship between the shrinkage product (S_P) and the grading coefficient (Gc) exhibits the performance of gravel wearing course materials. The system was developed from SA based on their condition where the G_C and the Sp should be in the range 16- 34 and 100-365 respectively (Table 1).

The BS test methods were used for laboratory tests. The recommended limit of Sp and Gc presented in Table 2 were compared to the results obtained. However, it should be noted that no modification made to Gc because a sieve of 28 mm was used in the placed of 26.5 mm. Fig. 4 presents the performance of the gravel wearing courses on the selected roads.

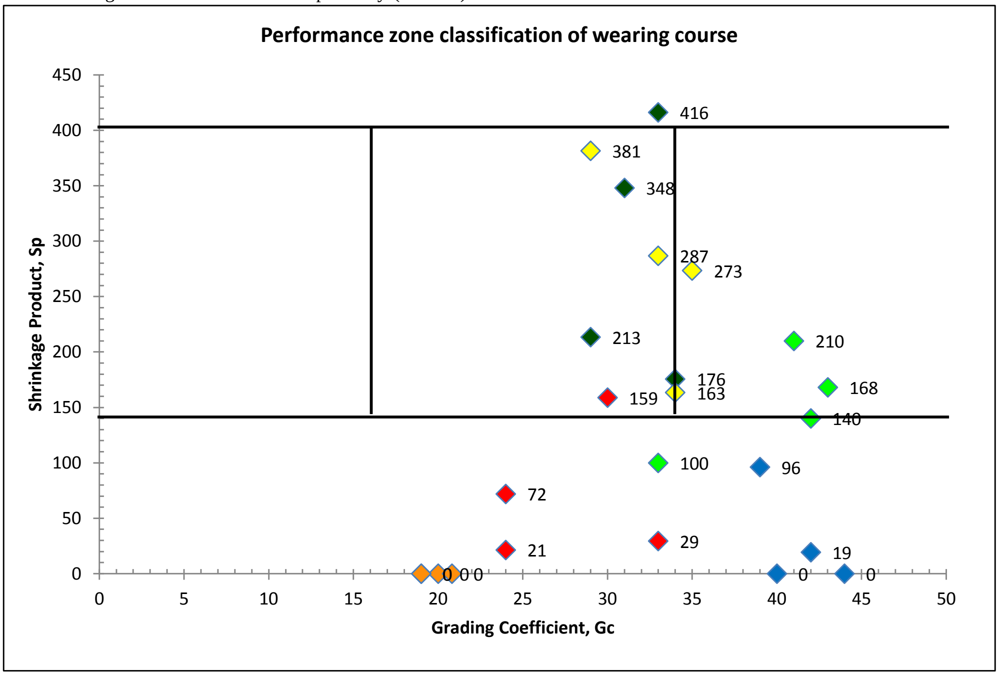

Fig. 4. Relationship between Gc and Sp and performance zones of surface material

Sandstone materials on gravel road Shakinyaga-Gashari and Karongi-Gasenyi have the Sp below 140 (except one sample having Sp=159) with grading coefficient within the recommended range i.e. 16-34. They are classified in Zone B. They lack cohesion and are prone to the formation of loose materials and corrugation. They require regular maintenance in respect to surface functional requirement i.e. roughness and riding quality. The volcanic gravels found in the North on road Nyagahondo-Nyabikenke and Sashwara-Kabatwa have the Gc between 33 and 43 with Sp in between 0 and 210. They are classified in Zone B and in Zone C. They are exposed to ravelling and loose materials due to lack of cohesiveness. The lateritic gravel road i.e. Kiruli-Kirambo and Kirambo-Gahunga are generally in Zone E. They present good performance. One sample is in Zone D where they may slip.

All sample materials are resistant to erosion because no material is classified into Zone A and the grading coefficients above the lower recommended limit. From field observations, the erosion defects were mainly due to poor drainage systems along the roads.

4.5.3. Performance zones with Visual Condition Index

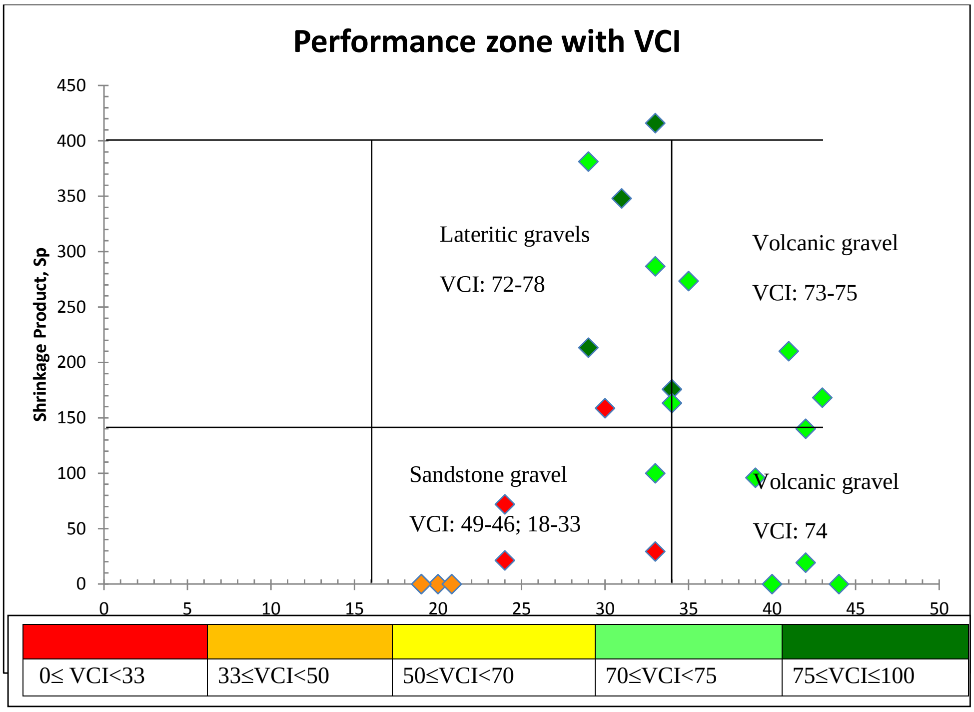

Fig. 5. Relationship between the Gc, Sp, performance zones and VCI

The Fig. 5 above presents the relationship between the performance zones with visual condition index. The data points are presented in colour with their corresponding VCI range.

The lateritic gravels on roads classified in Zone E have a good condition index i.e VCI in the range 70 – 85. The sandstones gravels in Zone B have poor condition index. Volcanic gravels generally classified in Zone C and in Zone B have good visual condition index. Although those volcanic gravels present good VCI, they are prone to ravelling with ageing.

Table 10: Gravel materials performance zones and condition category

Road	**Materials**	**Gc**	**Sp**	**Zones**	**VCI**	**Category**
Shakinyaga- Gashari	Sandstone	19-21	0	B	49-46	Poor to Fair
Karongi- Gasenyi	Sandstone	24-33	21-159	B	18-33	Very Poor
Nyagahondo-Nyabikenke	Scoria	39-44	0-96	B	74	Good
Sashwara-Kabatwa	Scoria	33-43	140-210	C	73-75	Good
Kiruli-Kirambo	Laterite	29-34	176-416	E	78	Good
Kirambo-Gahunga	Laterite	29-35	163-381	E	72	Good

5. CONCLUSIONS

The gravel materials tested were grouped in three groups: sandstones (at Shakinyaga-Gashari and Karongi-Gasenyi roads), volcanic gravel (scoria) (at Nyagahondo-Nyabikenke and Sashwara-Kabatwa roads) and lateritic gravel (at Kiruli-Kirambo and Kirambo-Gahunga roads). After a series of laboratory tests and field investigations the following conclusions can be drawn:

~~1.~~• The most distresses are the stoniness and loose materials resulting in poor riding quality for road in the central part of the Western province where the sandstones materials are the most available and used gravel wearing courses materials.

~~2.~~• Lateritic materials in the North Province indicated good performance than other materials. The average grading coefficients is 32. Their average shrinkage product is 282. In terms of wearing courses performance, they are classified in Zone E. The average dry density of these materials is 2.17 g/cm^3. Average optimum moisture content of 11%. The mean plasticity index is 15%, and average linear shrinkage 6%. They are classified in subgroups GC (clayey gravel with sand) as per AASHTO, A-2-4, A-2-6 and A- 6 as per USCS. With CBR they are from G6 to G8 according to TRH4. Thus, lateritic gravels are good materials for gravel wearing courses in the studied area with caution to limit the dustiness effects during dry season.

~~3.~~• The volcanic gravels or scoria are most used as gravel road materials in the North-West of Rwanda. They were found to be in Zone B and C. Scoria are having higher grading coefficient (average GC of 41) with low shrinkage product (average Sp of 98). They lack sufficient fines as binder. Hence they are prone to ravelling and formation of loose materials. The Gc and Sp are generally higher than the upper limit of grading coefficient specified in South Africa specification. The average dry density is 1.785 g/cm^3. The average CBR of these materials is 19%. The density and CBR are relatively low than other materials. They are found to have some mica content contributing to the reduction of cohesion and strength between particles.

~~4.~~• The sandstones gravel materials are found in the Central part of the West Province. They present high sand content causing the looseness of cohesions for surface gravel materials. They are classified in Zone B of performance in South Africa classification performance chart of unpaved road materials. The USCS classifies those materials as silty gravel with sand. They have good grading coefficient and are resistant to erosion but need blending with fines as binder to increase the cohesion. They are characterised by oversize particles. The average grading coefficients is 24. They are non-plastic gravel i.e. NP, having an average linear shrinkage of 1% and an average shrinkage product of 35. Their dry density is high and CBR considerably higher than other type of materials. The average dry density and CBR is 2 g/cm^3 and 55% respectively. They should be used as gravel wearing course materials with restriction of excessive loose surface gravels and stoniness with regular maintenance for good riding quality.

6. RECOMMENDATIONS

~~1.~~• Some gravels have gradings out of the suggested grading in TRH14 for gravel wearing courses materials but showing good grading coefficients. Gc values in the recommended range by TRH20, others have grading curves similar to the recommended Fuller's curve i.e. classified to be well graded, while having the grading coefficients above the upper limit of the recommended range. Therefore, the monitoring of the performance in a certain period for the local used materials in the construction of gravel road is required to revise or calibrate the existing specifications in terms of grading envelope for local available materials.

~~2.~~• The optimisation of the dust and sand ratios should be investigated for better selection of materials meeting criteria for limiting dust generation and loose small particle size on surface of unpaved roads and reducing the instability of surface materials due to high sand content or slipperiness during the wet season due to high dust or fines.

~~3.~~• The research focused on the analysis of grading, Atterberg limits, CBR and compaction, emphasizing on the grading coefficients, grading modulus, dust and sand ratio, plasticity behaviour, shrinkage product and the oversize index. The hardness of gravel is also a requirement of gravel materials. They control the resistance of gravel or aggregate to abrasion or degradation. It should be assessed for different gravel road materials especially for volcanic gravel from their nature where they are characterised by lack of binding properties or particle cementation and low density.

~~4.~~• Lateritic gravels were found to have high fine content whereas volcanic gravel (scoria) and sandstones were lacking binder. The blending of the volcanic gravel or sandstones with the lateritic gravel and their mix proportions may be investigate.

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