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Study to Improve Engineering Properties of the Mixtures of Cinder, Natural Pozzolana and Lateritic Soils for Construction of Surfacing Layers of Low Volume Roads in Mbeya Region Tanzania

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Abstract

The availability of suitable gravel materials for road construction that meet specified standards are becoming scarce and the use of available marginal materials shows challenges of not meeting engineering properties for construction of surfacing layers of Low Volume Roads (LVRs). This study aims at investigating the engineering properties of the mixtures of marginal materials which are natural cinder gravel, natural pozzolana and lateritic soils. Natural cinder and natural pozzolana were sourced from Ituha area in Mbeya Region and lateritic soils were sourced from Busale area in Tukuyu District Mbeya Region. In order to improve engineering properties of these marginal materials blending process of the three source materials was conducted. Characterization of source materials and four different blends which are 19La22Po59Ci, 21La20Po59Ci, 23La18Po59Ci and 25La16Po59Ci used for this study were conducted. The tests performed includes particle size distribution, Atterberg limit, compaction test and California bearing ratio. Laboratory test results indicates that all three source materials did not meet criteria to be used for construction of surfacing layer materials of LVRs in Tanzania. The results indicate that all four blends used for this study meet the specification as gravel materials for the construction of surfacing layers of LVRs in Tanzania. This is because the GC and SP values are within the recommended ranges and CBR values are above the minimum of 15%. From the results of this study, it is recommended to improve the engineering properties of marginal materials through blending techniques which could reduce the cost of construction and solve the challenge of scarce suitable materials in many areas in Tanzania.

Keywords: LVRs; lateritic soils; cinder; pozzolana; CBR; MDD; characterization; blending process; engineering properties.

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1. Introduction

Availability of suitable natural gravel materials for the construction of Low Volume Roads in most of the areas in Tanzania are becoming scarce. The functionality of LVRs in many areas in Tanzania is difficult due to the deterioration of pavement materials especially during rainfall seasons. Construction and maintenance costs of LVRS are becoming high due to the scarcity of suitable natural gravel and aggregate materials within the specified 10 km haulage distance especially in regions where the Great Rift Valley has passed through [1]. The depletion of suitable source materials is because of construction, mining and agricultural activities taking place in the daily lives of people. Gravel low volume roads (LVRs) are designed and constructed to serve up to 300 vehicles per day but are also capable of carrying up to 1.0 mil CESAL (cumulative equivalent standard axle loads) during their design life [2]. In Tanzania, the dominant road network is LVRs which takes about 75% of the whole road network and serves about 80% of the population in the country [3]. The construction and maintenance of LVRs in Tanzania is vital since they play a major role in the mobility of goods, people and agricultural inputs from urban markets to rural areas and agricultural products from rural areas to urban markets [4].Natural cinder and natural pozzolana materials are the results of volcanic activities due to eruption and cooling of magma [1, 5]. The cooled magma mixes with natural soils and the deposition process after a long time results in cinder gravels and pozzolanic soils [1]. Cinder gravels are volcanic materials which have high void contents that absorb high amounts of water, low specific gravity, relatively soft grains and have no binding properties [6]. Several studies in Africa are continuing to be conducted on the utilization of cinder materials as alternative materials for road construction [7, 8, 9]. The finding from several studies indicated that cinder materials are suitable to be used as surfacing layers and base layers of low volume roads when blended with other natural materials such as clays, laterite, pozzolana, etc or stabilized with cementitious materials such as lime, cement, a mixture of pozzolana and lime, etc [9, 10, 11, 12].

Most pozzolan soils are non-plastic to low plastic materials, but also they lack coarse particles in the grading curve which makes them unsuitable for LVRs because their plasticity indices are less than the recommended range of 6% to 12%, grading coefficients are lower than 16 units and shrinkage products are lower than 100 units minimum [1]. These shortfalls have resulted in a low or improper usage of volcanic materials in Tanzania [11, 13]. Natural cinder and natural pozzolanic materials have been categorized as marginal materials because they lack some engineering properties including binding and gradation characteristics to meet gradation coefficients and shrinkage products ranges [12].

Lateritic soils are residual soils that occur extensively in the humid tropical and sub-tropical zones of the world, including the central, southern, eastern and western parts of Africa and in Tanzania they are abundantly found in the southern regions. Lateritic soils are soils that have been produced by advanced weathering processes [7]. The lateritic soils are considered to be rich in iron and alumina minerals. They have unique characteristics in which some have high plastic index and some are non-plastic materials comprising of fine clay, silt, sand and gravel [14]. Due to their wide range of engineering properties lateritic soils are also considered as marginal natural materials for construction of LVRs [15].

For this study, the engineering properties of sources cinder, pozzolana and lateritic materials and of the blended sample materials for the construction of surfacing layers of LVRs were investigated under laboratory conditions. The laboratory tests conducted are Atterberg limits, particle size gradations, compaction tests and California bearing ratios (CBR values).

2. Investigation Procedure and Approach

The sample materials were collected from identified sources in Mbeya Region and laboratory tests were conducted to determine their engineering properties for single and for blended sample materials. The laboratory tests conducted were Atterberg limits, particle gradation, compaction parameters, and California bearing ratios for single and blended sample materials according to procedures stipulated in **[3].** The source materials investigated for this study are Ituha cinder, Ituha pozzolana and Busale lateritic soils. Characterization and strength properties of source materials and blended materials were investigated. Table 1 shows the types of source materials, physical characteristics and materials classification according to the AASHTO classification system.

Table 1: *Categorization of origin material*

Source materials	**Abbreviation**	**Physical properties**	**AASHTO Classification**	**% Fines**	**% Sand**	**% Gravel**
Cinder	Ci	Blackish gravel	A-1b Stone fragment, gravel and sand	14.0	9.9	76.1
Pozzolana	Po	Brownish color soil	A-4 Silt soil	60.0	32.2	7.8
Laterite	La	Reddish soil	A-7-6 Clayey soil	53.0	30.1	16.9

The source materials were blended at different proportions to meet the specified requirements of particle size gradation, shrinkage product (SP), grading coefficient (GC) and California bearing ratio (CBR) stipulated in several specification manuals for Low Volume Roads suitable for construction of surfacing layers [3, 8, 16]. The gradation envelopes for surfacing layer materials of LVRs with particle sizes from 0.01mm to 50 mm have been specified in [16] (refer to Figure 2). The grading coefficients (GC) and shrinkage products (SP) are computed by using equations 1 and 2 [3,8]

$$\mathrm{GC} = \frac{\mathrm{P4.75(P26.00-P2.00)}}{100} \qquad 1$$

$$\mathrm{SP} = \mathrm{P0.425SL} \qquad 2$$

Where: The letter "P" denotes percentage passing, the number in front of the letter "P" denotes sieve size in mm and SL denotes shrinkage limit.

The three source materials which are cinder, pozzolana and lateritic soils were blended in order to suit gradation envelopes, grading coefficients, shrinkage products and CBR values. Equation 3 was used to determine the proportions of source materials for the blending process [1].

$$P_A = \frac{260-(GC_B+SP_B)}{(GC_A+SP_A)-(GC_B+SP_B)} \text{ and } P_B = 1 - P_A \qquad 3$$

Where: PA and PB are proportions of material A and B respectively in decimal, GCA and GCB are grading coefficients of material A and B respectively, SPA and SPB are the shrinkage products of materials A and B respectively.

3. Results and Discussion

3.1. Results of Source Materials

The analysis of laboratory tested sample materials was based mainly on the parameters required for the selection of materials to be used for the construction of surfacing layers of unbound low volume roads (LVRs) which are grading envelopes, shrinkage products (SP), grading coefficient (GC) and California bearing ratios (CBR). In order to obtain the specified engineering parameters for the construction of surfacing layers of LVRs, characterization and analysis of tested data were performed.

3.2. Characterization of Source and Blended Materials

Atterberg limits tests were conducted for source and for blended materials to determine plasticity indices (PI) and linear shrinkage (LS) limits. Table 2 gives the results of Atterberg limit tests for three source materials. Results indicate that Busale lateritic soils have a high PI value of 33%, Ituha cinder and Ituha pozzolan are non-plastic materials on which all three source materials are not suitable as surfacing materials for LVRs [3, 8]. The recommended PI values for gravel materials to be used for the construction of surfacing layers of LVRs is 6% to 12% [17]. The materials having high PI values result in slippery roads during rainfall and dusty roads during the dry season associated with rapid loss of surfacing materials. However, non-plastic materials result in corrugations and raveling associated with the loss of gravel particles [3, 18]. In order to enhance the binding properties of these marginal materials it was necessary to blend them at the desired proportions.

Table 2: Atterberg limit data of source materials

Source materials	**Abbreviations**	**Liquid limit (LL) (%)**	**Plastic limit (PL) (%)**	**Plasticity index (PI) (%)**	**Linear shrinkage limit (SL) %**
Ituha cinder	Ci	Non-plastic	Non-plastic	Non-plastic	0
Ituha pozzolan	Po	Non- plastic	Non-plastic	Non-plastic	0
Busale laterite	La	68	35	33	18

Gradation and particle size analysis tests for the source and for the blended materials were conducted to determine particle size distribution, grading coefficients "GC" and shrinkage product "SP", and for classification purposes based on AASHTO classification (refer to Table 1). Table 3 shows the percentage passing to sieve sizes 26 mm, 4.75 mm, 2.00 mm and 0.425 mm and computed grading coefficients and shrinkage products for each source material.

Table 3: Particle size data, grading coefficients and shrinkage product results of source materials

Source materials	Abbrev -iations	Percentage Passing on Sieve Sizes					Grading Coefficient (GC)	Shrinkage Product (SP)
		26 mm	4.75 mm	2.0 mm	0.425 mm	0.075 mm		
Ituha cinder	Ci	99.6	49.4	23.9	16.1	14.1	37.3	0
Ituha pozzolana	Po	100	95.6	92.2	80.3	60.2	7.5	0
Busale laterite	La	100	88.8	83.1	69.2	53.0	15.0	1244.7

Grading coefficients (GC) and shrinkage products (SP) of all three source materials are out of the range of 16 to 34 units and 100 to 365 units respectively (refer to Table 3) which indicates that these marginal source materials are not suitable for construction of LVRs.

Table 4: Particle sizes, grading coefficients and shrinkage products of blended materials

Blended materials	Percentage passing on sieve sizes				Plasticity index (PI)	Linear shrinkage (LS)	Grading coefficient (GC)	Shrinkage product (SP)
	26 mm	4.75 mm	2.00 mm	0.425 mm				
19La22Po59Ci	99.7	67.0	50.2	40.3	6.27	3.42	26.50	236.49
21La20Po59Ci	99.8	66.9	50.0	40.1	6.93	3.78	26.65	261.39
23La18Po59Ci	99.7	66.7	49.8	39.9	7.59	4.14	26.81	286.25
25La16Po59Ci	99.7	66.5	49.6	39.6	8.25	4.50	26.96	311.18

Table 4 shows the percentage passing to sieve sizes 26 mm, 4.75 mm, 2 mm and 0.425 mm and computed grading coefficients and shrinkage products for the four blended materials which are 19La22Po59Ci, 21La20Po59Ci, 23La 18Po59Ci, 25La16Po59Ci. The grading coefficients (GC) and shrinkage products (SP) for all four blend sample materials are within the range of 16 to 34 units and 100 to 365 units respectively (refer to Table 4).

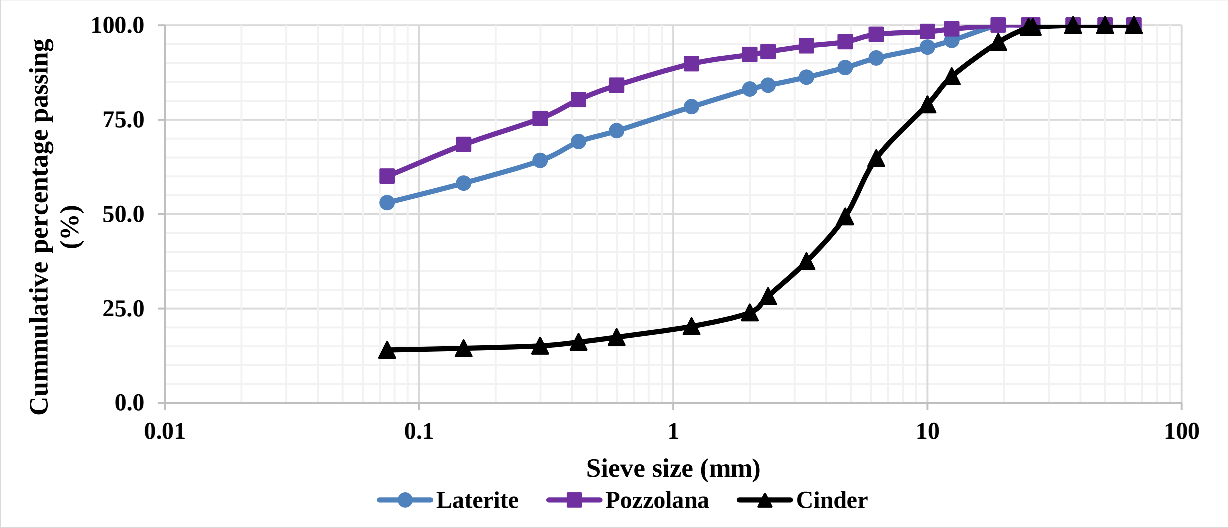

Figure 1: Particle size distribution curves of source materials

Therefore, this indicates that when marginal materials are well blended together, they meet the engineering properties required for the construction of the surfacing layer of LVRs [3,16, 18]. Figure 1 shows particle size distribution curves of three source materials used for this study which are lateritic, cinder and pozzolana. For this study, it has been investigated that all three source materials do not lay within the specified envelope. To enhance interlocking and friction resistance of particles it is recommended that gradation curves of soil samples should lay within the specified envelopes for surfacing layers of LVRs [1, 16]. Three source materials were blended by using equation 1 to obtain four different sample specimens which are 19La22Po59Ci, 21La20Po59Ci, 23La 18Po59Ci, 25La16Po59Ci. Figure 2 shows particle size distribution curves of four blended sample materials. Particle size gradation conducted for the blended samples indicated that all four blend materials lay within the envelope specified for surfacing layers of LVRs [16].

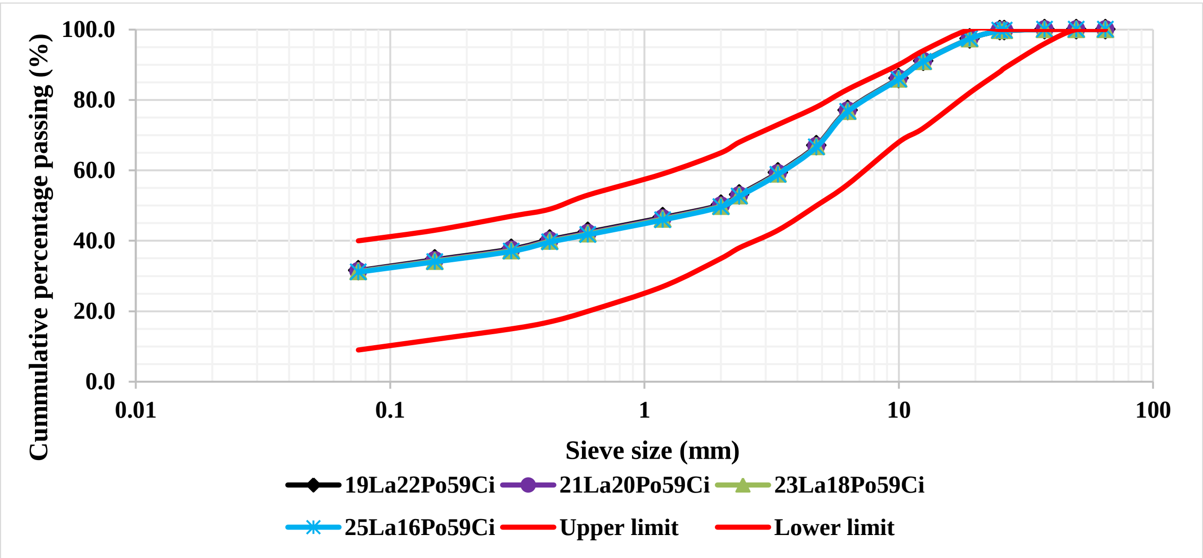

Figure 2: Particle size distribution curves of blended material

3.3. Compaction Tests of Source and Blended Materials

Compaction tests for three source materials and for the four blends materials were conducted using a modified BS heavy proctor test to determine maximum dry densities (MDD) and optimum moisture contents (OMC). The results for maximum dry densities and optimum moisture contents for the three source materials obtained are 1755 kg/m^3 and 14% for cinder, 1470 kg/m^{33} and 27% for pozzolana and 1530 kg/m^3 and 22.5% for lateritic soils. Figure 3 shows the compaction curves of three sources materials whereby the turning points of the curves indicate their maximum dry densities and optimum moisture contents.

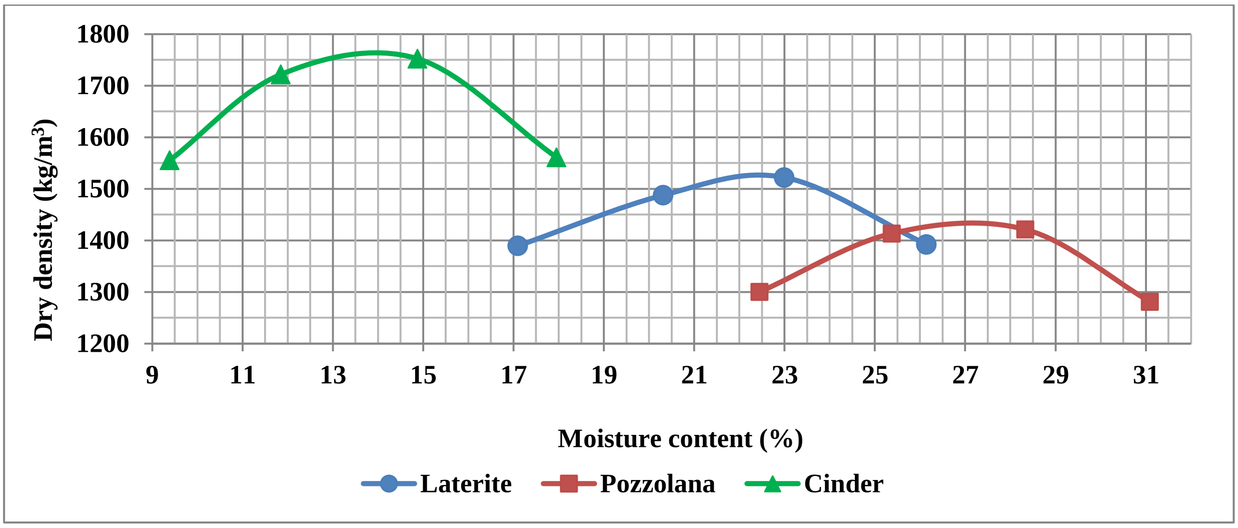

Figure 3: Compaction curve of source material

The compaction tests for all four blended materials were conducted using modified BS heavy proctor test to determine maximum dry densities (MDD) and optimum moisture content (OMC). The results of maximum dry densities and optimum moisture contents obtained for 19La22Po59Ci are 1650kg/m^3 and 17.6%, for 21La20Po59Ci are 1630 kg/m^3 and 18.0%, for 23La18Po59Ci are 1625 kg/m^3 and 18.2%, for 25La16Po59Ci are 1620 kg/m^3 and 17.7%. The results indicate that there are little variation of maximum dry densities and optimum moisture contents of blended sample materials. This is because the mixtures contain the same amount of cinder and little changes of laterite and pozzolana materials. Figure 4 shows the compaction curves of four blended sample materials which indicates their maximum dry densities and optimum moisture contents at turning points.

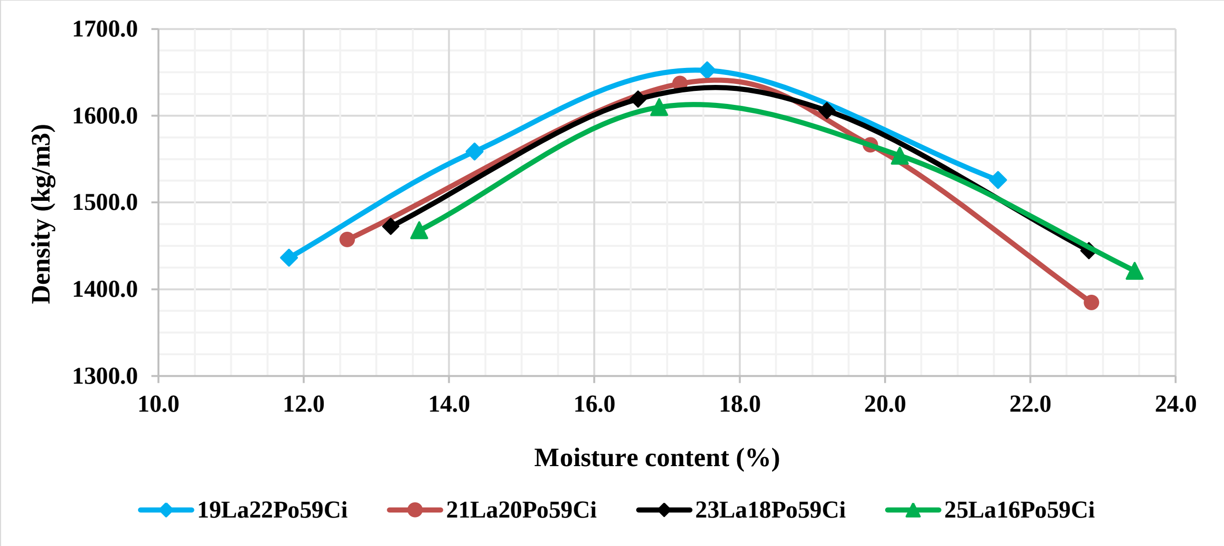

Figure 4: Compaction curves of blended materials

The three point California bearing ratio tests for three source materials and for the four blends materials were conducted using modified BS heavy density to determine CBR values at 95%MDD [3].

3.4. California Bearing Ratio of Source and Blended Materials

Source materials and blended materials were mixed and compacted at optimum moisture contents, and then soaked in water for 96 hours and penetrated by using a CBR machine to read resisting shearing forces for each plunger penetration depth. The materials in the first mould were compacted using 4.5 kg pistol weight, 62 blows for 5 layers, the materials in the second mould were compacted using 4.5 kg pistol weight, 30 blows for 5 layers and the materials in the third mould were compacted using 2.5 kg pistol weight, 62 blows for 3 layers [19]. The three point CBR test is conducted to determine variation of material strength with degree of compaction. The average CBR values were calculated from the forces obtained at 2.5 mm and 5.0 mm plunger penetration depths [19].

The results of CBR values at 95%MDD for three source samples materials obtained for this study are 18% cinder, 23% pozzolana and 7.2% laterite soils. The high CBR value was indicated for pozzolana followed by cinder and laterite soil indicated low CBR values which is probably due to high soaking rate of clayey laterite soil [9]. Figure 5 shows three points CBR values of the three source materials. The results indicated that cinder and pozzolana materials have CBR values greater than 15% minimum recommended for the construction of surfacing layers of LVRs. However, all three source sample materials did not qualify for the construction of surfacing layers of LVRs because they do not meet one or some of the engineering properties which include PI, GC. SP, CBR and gradation envelopes.

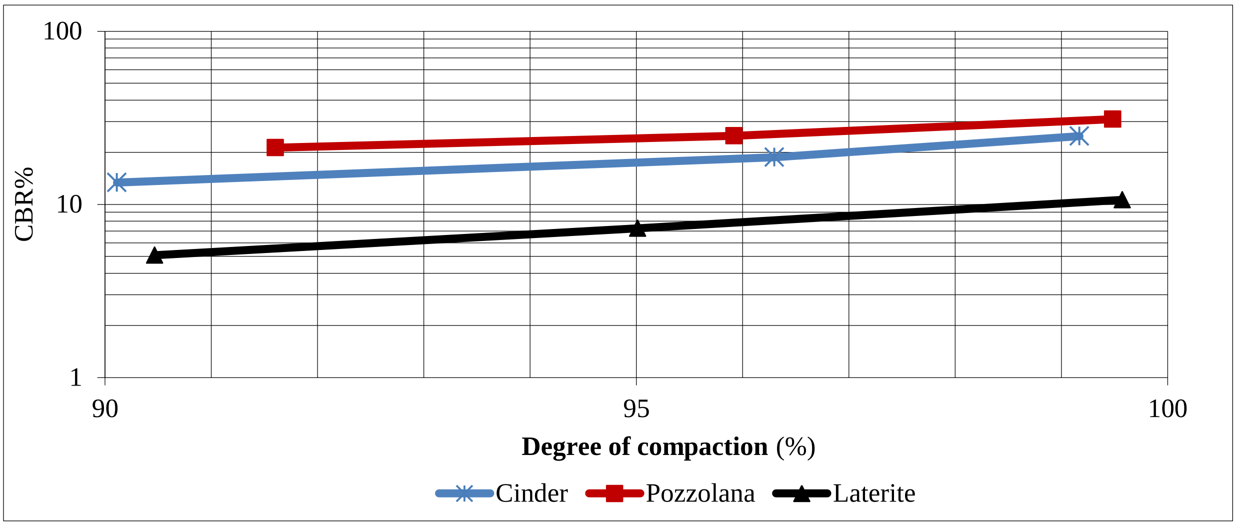

Figure 5: Three points CBR values of source materials

Therefore, through blending process of the source materials enhanced missing properties from each other to obtain materials which possess the required engineering parameters for the construction of LVRs. Figure 7, 8 and 9 shows photos of source materials and graphs of penetration resistances of CBR tests for Busale laterite, Ituha pozzolana and Ituha cinder respectively.The results of soaked CBR values at 95%MDD for the four blended samples are 23.6% for 19La22Po59Ci. 22.8% for 21La20Po59Ci, 22.7% for 23La18Po59Ci and 21.9% for 25La16Po59Ci14La14Po72Ci which are above the recommended value of 15%. Figure 6 shows the three points CBR values of the four blended materials. From the given ranges of grading coefficients "GC", shrinkage products "SP", gradation envelopes and California bearing ratio "CBR values" it is indicated that all four blended materials are suitable to be used for the construction of surfacing layers of LVRs.

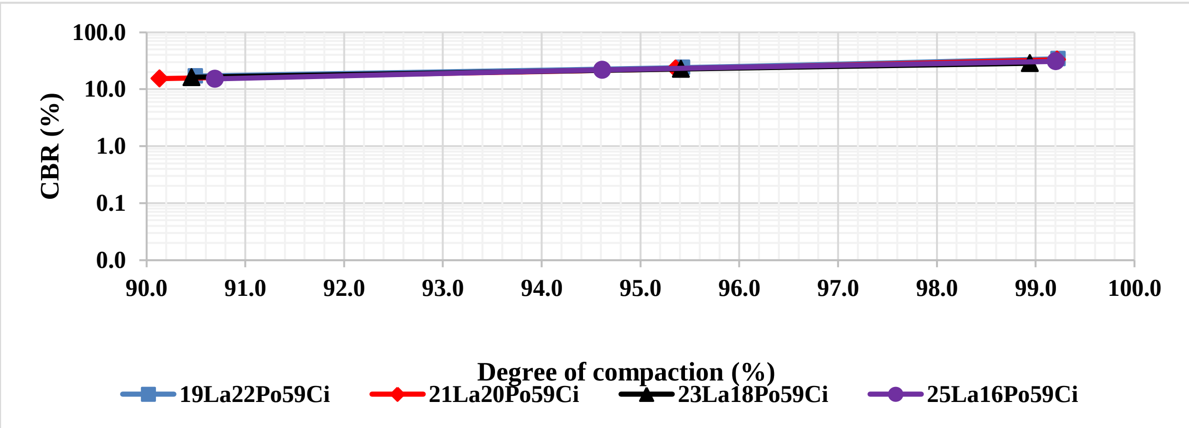

Figure 6. Three points CBR values of blended materials

This is because the GC of the materials is within the range of 16 to 34 units, shrinkage products are within the range of 100 to 365 units, gradations of blended sample materials lies within the specified envelopes and CBR values are above 15%. Figure 10 and Figure 11 are graphs of penetration resistances of CBR tests for the four blended sample materials which are 19La22Po59Ci. 21La20Po59Ci, 23La18Po59Ci and 25La16Po59Ci14La14Po72Ci respectively.

4. Conclusions and Recommendations

The costs of construction and maintenance of LVRs in Tanzania has become higher due to scarcity of suitable natural gravel materials. Suitable gravel materials are continuing to be depleted due to construction, agricultural and mining activities in most of the areas. To mitigate the challenge of scarcity suitable conventional materials for road construction and maintenance, the investigation on three marginal materials which are cinder gravel, pozzolana and lateritic soils were conducted in each source marginal material, blended, and laboratory tests for marginal source materials and for the blended materials were conducted to determine the engineering properties of four blends materials. Characterization and determination of CBR values of cinder, natural pozzolana material, laterite and blended soil materials were conducted under laboratory condition.The results from data analysis of three source materials indicated that the grading coefficients (GC) and shrinkage products (SP) are 37.3 units and 0 unit for cinder materials; 7.5 units and 0 units for pozzolana materials and 15 units and 1245 units for lateritic materials respectively. The CBR values of source materials are 18% for cinder materials, 23% for pozzolana materials and 7.2% for lateritic soils. The CBR values of cinder and pozzolana materials are above the recommended minimum of 15% for the construction of gravel wearing layers but GC and SP for all three source materials are outside specified ranges of 16 units to 34 units and 100 units to 365 unit respectively.The GC, SP and CBR of the four blends determined for this study are 26.5 units, 236.5 units and 23.6% for 19La22Po59Ci; 26.7 units, 261.4 units and 22.8% for 21La20Po59Ci; 26.8 units, 286.3 units and 22.7% for 23La18Po59Ci and 27 units, 311.3 units and 21.9% for 25La16Po59Ci14La14Po72C respectively. The results indicate that all four blends used for this study meet the specifications as gravel materials for the construction of surfacing layers of LVRs in Tanzania. It is recommended that the engineering properties of marginal materials be improved through blending and stabilization techniques which could reduce the cost of construction and solve the challenge of scarcity of suitable materials in many areas in Tanzania.

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Appendix

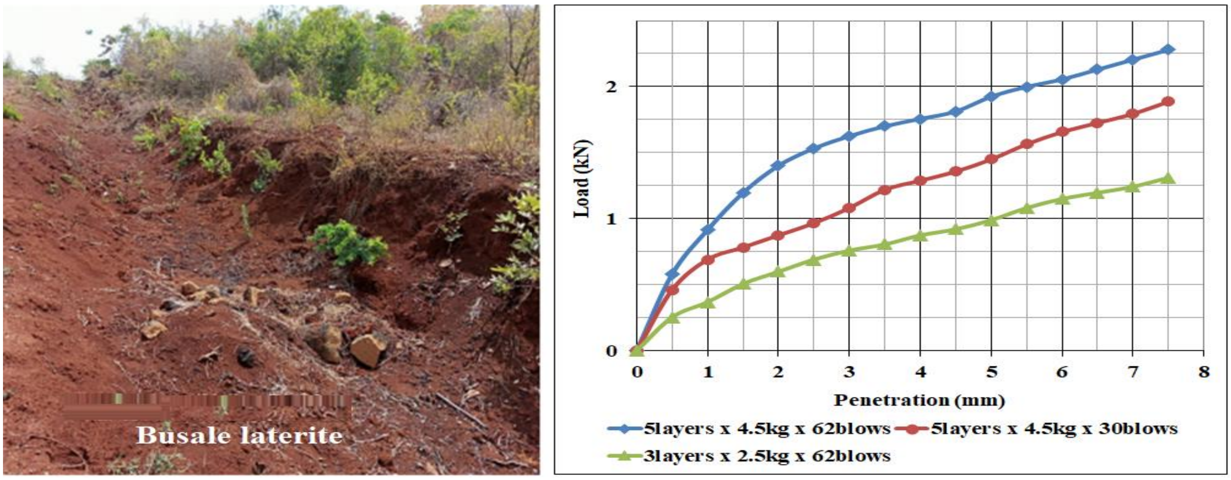

Figure 7: Photo for source laterite materials (left) and Penetration resistance of Laterite materials (right)

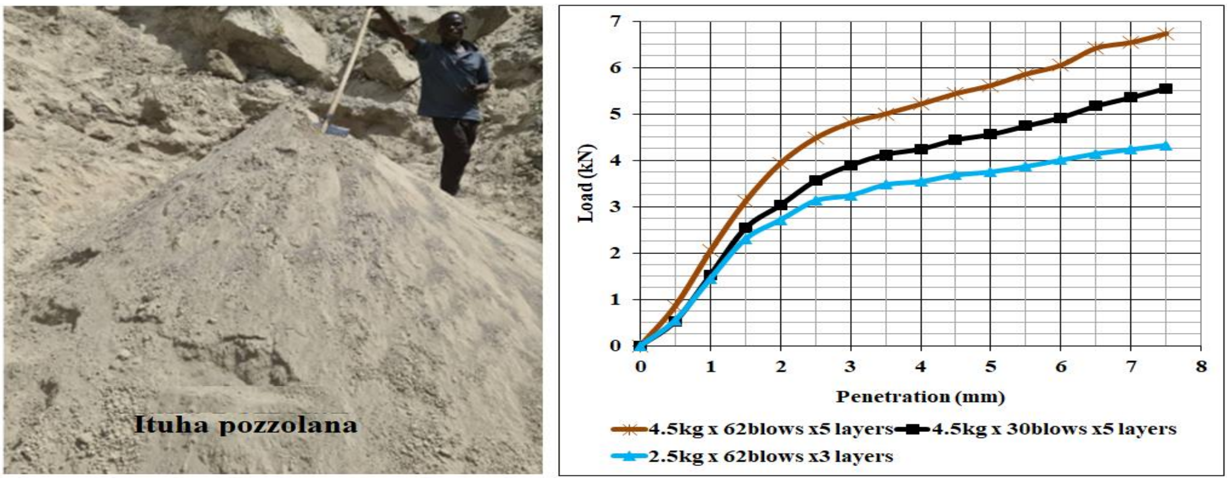

Figure 8: Photo for source pozzolana materials (left) and Penetration resistance of pozzolana materials (right)

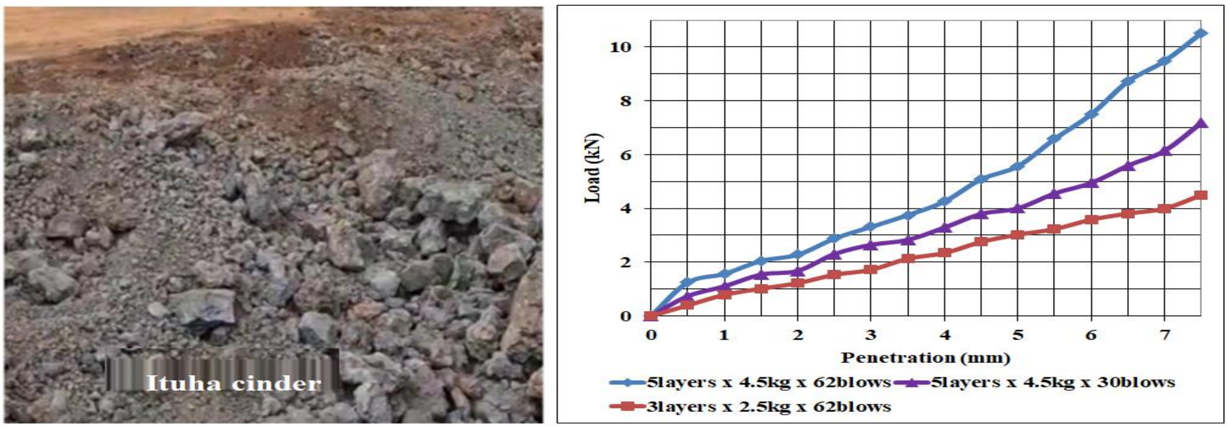

Figure 9: Photo for source cinder materials (left) and Penetration resistance of cinder materials (right)

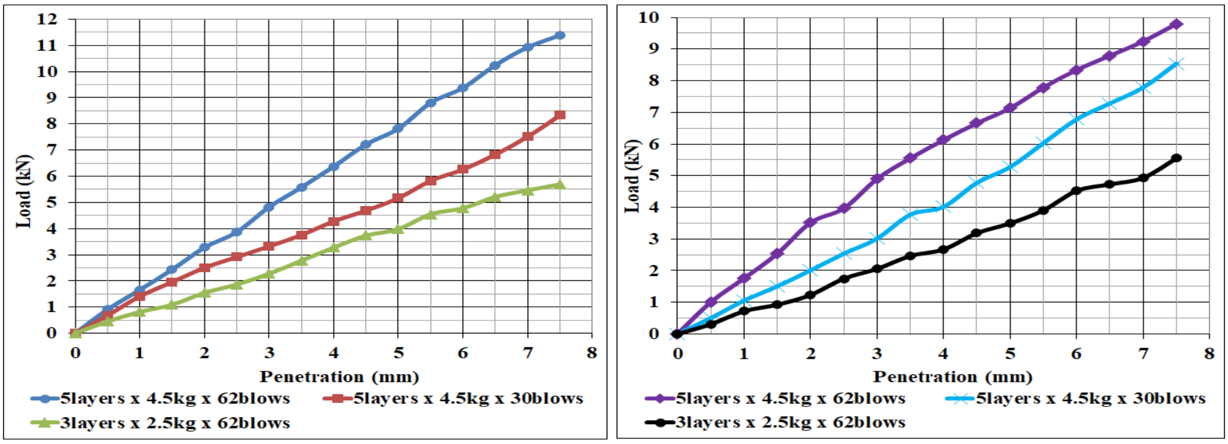

Figure 10: Penetration resistance of 19La22Po59Ci (left) and 21La20Po59Ci (right)

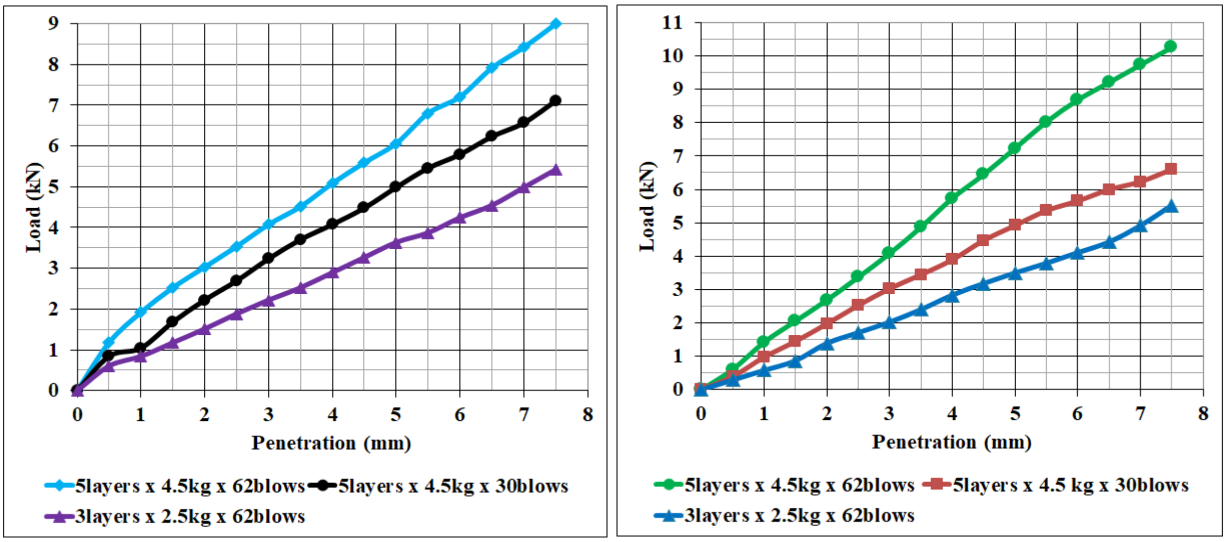

Figure 11: Penetration resistance of 23La18Po59Ci (left) and 25La16Po59Ci (right)