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Research/Technical Note

Improving Properties of Cinder Blended Materials for Construction of Low Volume Roads in Mbeya Region Tanzania

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Abstract: The study to improve engineering properties of cinder blended materials was conducted in Mbeya region Tanzania. The low volume roads (LVRs) comprises of 75% of the whole road network and serves about 80% of population in Tanzania. The abundant materials in Mbeya region are cinders/scoria, pumices and volcanic soils which are originated from volcanic action. The samples from four source materials which are Ituha cinder, Ituha pozzolan, Mlimanyoka clay and Mbalizi gravel were collected for laboratory tests. Characterizations of source materials were conducted and grading coefficients (GC) and shrinkage products (SP) which are the requirements for selection of materials for surface layers of LVRs were computed. The results for GC and SP for all four source materials are out of range of 16 to 34 units and 100 to 365 units respectively. The California bearing ratios (CBR) at 95%MDD (maximum dry density) for four source materials are 17.6% for Ituha cinder, 25% for Ituha pozzolan, 3.2% for Mlimanyoka clay and 5.1% for Mbalizi gravel. The results for GC, SP and CBR for all four source materials indicated that the materials are not suitable for construction of surface layers of LVRs. The four source materials were blended together to get six blended sample materials targeting GC and SP ranges. The results of CBR values at 95%MDD for the six blended samples are 28% for 10MNCl40ITPo50ITCi0MBGr, 43% for 11MNCl40ITPo39ITCi10MBGr, 56% for 12MNCl35ITPo40ITCi13MBGr, 44% for 13MNCl32ITPo35ITCi20MBG, 39% for 14MNCl42ITPo44ITCi0MBGr and 53% for 15MNCl25ITPo35ITCi25MBGr. The improvement of CBR values of the six blended sample is because of enhanced interlocking and friction properties of the mixtures and addition of clay which act as binder to the coarse grain particles. It is important to develop suitable envelopes for surfacing layer materials of LVRs since interlocking and friction resistance are enhanced by gradation characteristics of material grain particles. For easy blending process of materials, an equation have been developed which can be used to blend materials using GC and SP parameters.

Keywords: LVRs, Cinders, Pozzolan, Gravel, CBR, MDD, Volcanic Soils

1. Introduction

Low volume roads (LVRs) are the roads which are designed and constructed to serve 50 – 300 vehicles a day with pavement layers and materials capable to resist vehicle axle loads up to 1.0 mil CESAL (cumulative equivalent standard axle loads) during its design life [1, 3]. In Tanzania the LVRs comprises of 75% of the whole road network [1] and these LVRs play major role of mobility of goods, people and agricultural inputs from urban market to rural areas. In Tanzania about 80% of population lives in rural areas where the major economic activity conducted in rural areas is agriculture [7, 13]. The LVRs are not smoothly used throughout the year especially during rainfall due to high cost of construction contributed by unavailability of suitable conventional materials especially in Mbeya, Songwe, Arusha, and Kilimanjaro regions where the great rift valley have passed through [11].

The deposit materials available in Mbeya region are volcanic materials which are cinder/scoria gravels, volcanic soils and pumices [8, 11]. These materials have been categorized as marginal materials because they lack some engineering properties to be used for road construction [14]. Cinder gravels are volcanic materials with physical properties different from other natural gravels that are normally used for construction of LVRs. They have high void contents which absorbs high amount of water, low specific gravity, relatively soft grains and have no binding properties [2, 4]. These shortfalls have resulted into a low or improper usage of volcanic materials in Tanzania.

The cinder gravel are relatively stronger than pumice and soils which when properly blended with other materials can fulfill engineering requirements for construction of bases and surfacing layer of LVRs [5, 14]. Several studies conducted to improve engineering properties of cinder gravel materials have found to be suitable for construction of LVRs [2, 3, 6, 14].

For this study, the engineering properties of cinder blended materials for construction of LVRs were investigated under laboratory condition. The Atterberg limits, particle gradation, compaction parameters and California bearing ratios (CBR values) of single source and for blended materials were determined.

2. Investigation Procedure and Approach

2.1. Investigation Procedure

The investigation for this study involved identification of source materials, locations and classification based on AASHTO classification system. Samples from four source materials available in Mbeya region were taken to laboratory for investigation. The source materials investigated are Ituha cinder abbreviated as “ITCi”, Ituha pozzolana abbreviated as “ITPo”, Mlimanyoka clay abbreviated as “MNCl” and Mbalizi gravels abbreviated as “MBGr”. Characterization and strength properties of source materials and for blended materials were investigated. Table 1 shows source materials, physical characteristics and type of materials for road construction according to AASHTO classification system.

Table 1. *Classification of source materials (AASHTO).*

Source materials	Abbreviation	Physical properties	AASHTO Classification	% Fines	% Sand	% Gravel
Ituha Cinder	ITCi	Blackish gravel	A-1-b Stone fragment, gravel and sand	29	15	56
Ituha Pozzolan	ITPo	Brownish color soil	A-4 Silt soil	77	15	8
Mlimanyoka Clay	MNCl	Reddish brown soil	A-7-6 Clayey soil	87	12	1
Mbalizi Gravel	MBGr	Reddish brown gravel	A-2-7 Silt/clayey gravel sand	36	13	51

2.2. Investigation Approach

The sample materials were taken from the sources and the laboratory tests were conducted to determine their engineering properties required for materials to be selected for construction of surfacing layers of LVRs. The laboratory tests were conducted for single source materials and for blended materials. The laboratory tests conducted for source materials are particle size analysis, Atterberg limits (liquid limit, plastic limit and linear shrinkage limit), compaction tests and California bearing ratio (CBR values) tests.

The source materials were blended together at different proportions to meet the requirements of shrinkage product “SP” and grading coefficient “GC” stipulated in manuals for Low Volume Roads suitable for construction of surfacing layers [15]. The tests conducted for blended materials are particle size analysis, compaction tests, California bearing ratios and determination of shrinkage products and grading coefficients. The shrinkage product limits expresses binding properties of materials and grading coefficient limits expresses packing and interlocking properties of granular materials to be used for construction of surfacing layer of LVRs [15].

Sieve analysis tests were conducted to determine particle size gradations and percentages passing each sieve size. Percentage passing for some individual sieve sizes are used to compute shrinkage products and grading coefficients [15, 16]. The Atterberg limits involved determination of liquid and plastic limits used to compute plasticity index and determination of linear shrinkage limit. Plasticity index is used as indication of binding properties of materials and linear shrinkage limit is used as indication of shrinkage and swelling potential of the materials under changing weather environments. But also shrinkage limits of materials are used to compute shrinkage products. The compaction tests were conducted to determine maximum dry densities (MDD) and optimum moisture contents (OMC) of materials which are useful parameters when conducting California bearing ratio (CBR) tests. For this study a CBR values at 95% MDD were considered as strength of the materials [1, 15].

3. Results and Discussion

3.1. Results of Source Materials

The analysis of laboratory tested sample materials were based mainly on the parameters required for selection of materials to be used for construction of surfacing layers of unbound low volume roads (LVRs) which are shrinkage products (SP), grading coefficient (GC) and California bearing ratios (CBR). The limits of shrinkage products and grading coefficients for good performance of unpaved gravel roads ranges between 16 to 34 units and between 100 to 365 units for rural roads, but also the CBR values at 95%MDD should be greater than 15% [1, 15]. In order to obtain these specified engineering properties of materials for construction of surfacing layers of LVRs, characterization and analysis of tested data were performed.

3.1.1. Characterization of Source Materials

The source materials which were tested to determine engineering parameters are Ituha cinders, Ituha pozzolan, Mlimanyoka clay and Mbalizi gravel. The Atterberg limits tests were conducted for source materials to determine plasticity indices and linear shrinkage limits. Table 2 gives results of Atterberg limit tests for four materials. The results indicates that Ituha cinder and Ituha pozzolan are non-plastic materials which are not suitable as surfacing materials for LVRs [1, 15]. These materials requires addition of clay fines in order to enhance their binding properties. However, the plasticity indices (PI) of Mlimanyoka clay and Mbalizi gravel are 26.3% and 26.8% respectively which are above 12% recommended for unbound layers [10]. The materials having high PI values results into slippery of the road during rainfall and dusty during dry season associated with rapid loss of surfacing materials [1, 15]. In order to reduce higher PI values of Mlimanyoka clay and Mbalizi gravel it was necessary to blend with the materials having no plasticity which are Ituha cinder and Ituha pozzolan.

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	ITCi	Non-plastic	Non-plastic	Non-plastic	0
Ituha pozzolan	ITPo	Non-plastic	Non-plastic	Non-plastic	0
Mlimanyoka clay	MNCl	46.6	20.4	26.3	13.8
Mbalizi gravel	MBGr	49.4	22.7	26.8	12.9

The particle size analysis tests for source materials were conducted to determine particle size gradation and percentage passing for sieve sizes 26mm, 4.75mm, 2mm and 0.425mm which are used to compute grading coefficients "GC" and shrinkage product "SP". But also the percentage passing for individual sieve sizes together with Atterberg limits are used to classify the materials (refer table 1) based on AASHTO classification system. The grading coefficient "GC" and shrinkage product "SP" are computed using equation 1 and 2 [16, 15]

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

Where: Letter "P" denotes percentage passing and number in front of letter "P" denotes sieve size in mm.

$$SP = P0.425SL \quad (2)$$

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

Table 3 shows the percentage passing to sieve sizes 26mm, 4.75mm, 2mm and 0.425mm 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)
		26mm	4.75mm	2.00mm	0.425mm		
Ituha cinder	ITCi	99.1	70.7	43.8	31.2	39.0	0.0
Ituha pozzolan	ITPo	100.0	95.4	91.7	84.0	7.9	0.0
Mlimanyoka clay	MNCl	100.0	99.8	98.6	92.8	1.4	1282.6
Mbalizi gravel	MBGr	75.5	57.1	49.5	41.1	14.5	528.4

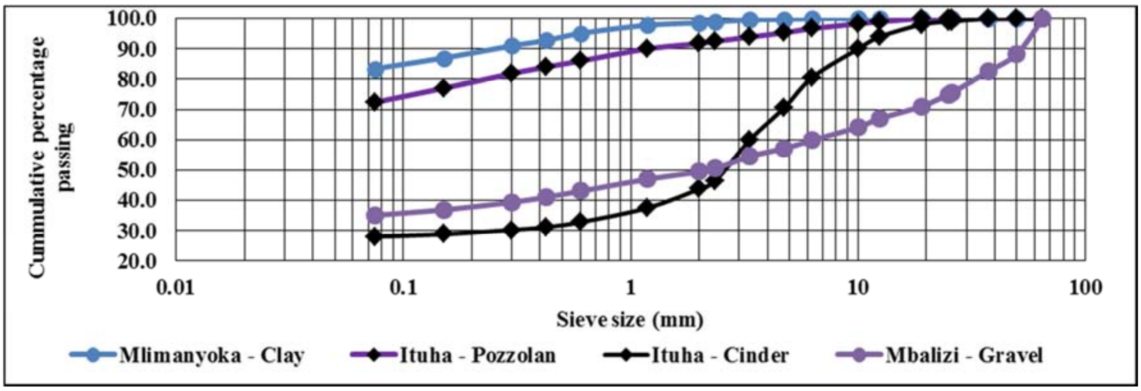

Figure 1. *Particle size distribution curves of source materials.*

The average particle sizes of four source materials are 0.53mm for Mlimanyoka clay, 1.85mm for Ituha pozzolan, 5.89mm for Ituha cinder and 19.42mm for Mbalizi gravel. Figure 1 is particle size distribution curves of the four source materials.

The grading coefficients "GC" and shrinkage products "SP" of all four source materials which are Ituha cinder, Ituha pozzolan, Mlimanyoka clay and Mbalizi gravel are out of range of 16 to 34 units and 100 to 365 units respectively. Then according to low volume road manuals, all four source materials are not suitable to be used for construction of surfacing layers [1, 15]. Figure 2 gives the range of shrinkage products and grading coefficients of materials to be used for construction of surfacing layer of LVRs [15, 16]. Figure 2 indicates that the materials having shrinkage products and grading coefficients laying within zone E they are suitable materials for surfacing layers, those laying outside zone E are considered to be unsuitable materials because during service time of the pavement they will develop various pavement defects including raveling, corrugation, slippery, erosion gullies, potholes etc [15].

The use of poor materials for construction of road pavement layers increases life cycle cost of the project because there will be premature failures of the pavement and frequency maintenance resulting into increased cost of road projects. Highly defected road pavements causes high vehicle operating costs due to frequent vehicle break down, accidents and fuel consumption [5, 12].

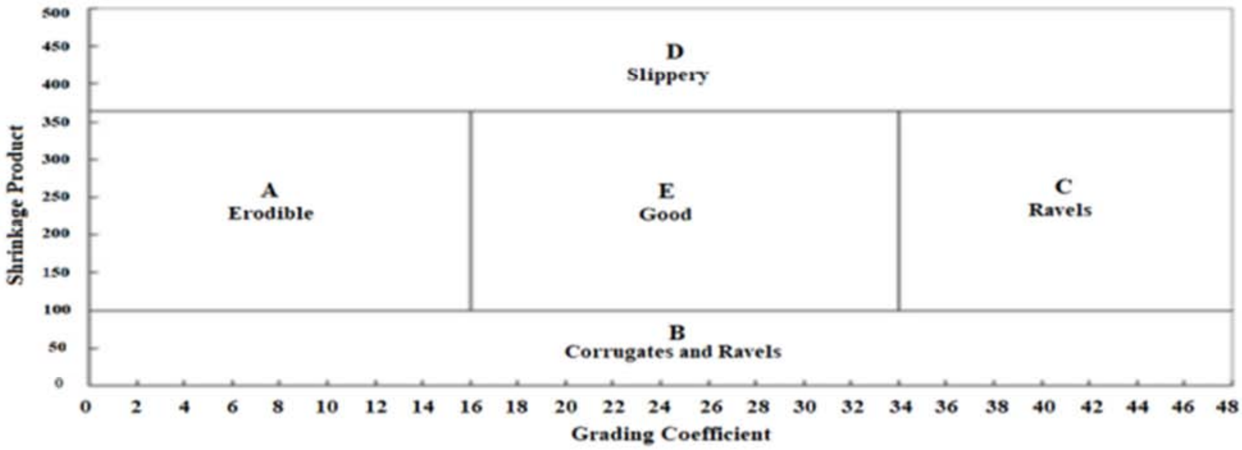

Figure 2. *Relationship between grading coefficient, shrinkage product, and performance.*

Compaction and California bearing ratio tests were conducted for source materials to determine their strengths in terms of CBR values at 95%MDD [1, 15]. For LVRs the materials having CBR values above 15% at 95%MDD are considered to be strong to resist traffic loading and can be used for construction of surface layers of LVRs provided that they meet GC and SP specifications [1, 15].

3.1.2. Compaction and California Bearing Ratio (CBR) of Source Materials

The compaction tests for all four source materials were conducted using modified BS heavy proctor test to determine maximum dry densities (MDD) and optimum moisture contents (OMC) [9]. The results for maximum dry densities and optimum moisture contents obtained for Ituha cinder are 1650kg/m^3 and 13%, for Ituha pozzolan are 1505kg/m^3 and 19.2%, for Mlimanyoka clay are 1500kg/m^3 and 23.4% and for Mbalizi gravel are 2100kg/m^3 and 11.3% respectively. For this study high MDD was for Mbalizi gravel followed by Ituha cinder this is due to high amount of large particle sizes compared to Ituha pozzolan and Mlimanyoka clay (refer table 1 and figure 1). Figure 3 shows the compaction curves of four sources materials where by the turning points of the curves indicates their maximum dry densities and optimum moisture contents. The three point California bearing ratio tests for four source materials were conducted using modified BS heavy density to determine CBR values at 95%MDD [1, 9, 15]. The materials were mixed and compacted at optimum moisture contents and soaked in water for 96 hours and penetrated to read resisting shearing forces for each plunger penetration depth. The average CBR values are calculated from the forces obtained at 2.5mm and 5.0mm plunger penetration depths.

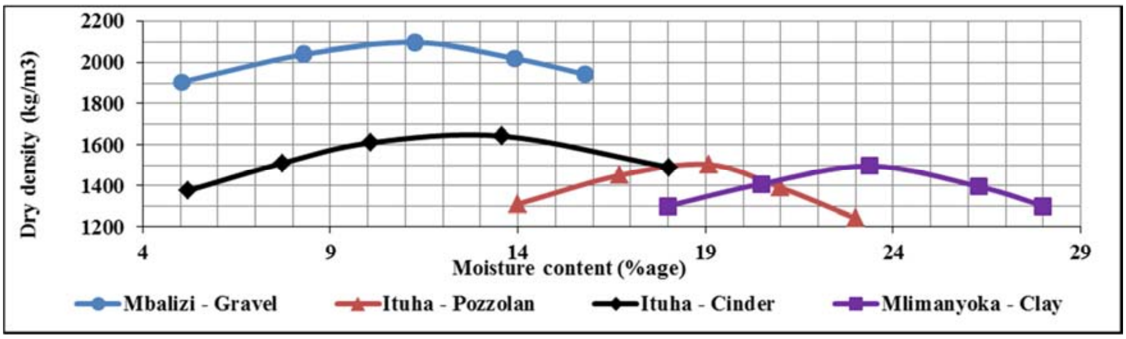

Figure 3. *Compaction curves of source materials.*

For three point CBR tests of the sample materials, three different compaction efforts and layer thickness of the same material are used.

The materials in the first mould is compacted using 4.5kg pistol weight, 62 blows for 5 layers, the materials in the second mould is compacted using 4.5kg pistol weight, 30 blows for 5 layers and the materials in the third mould is compacted using 2.5kg pistol weight, 62 blows for 3 layers. The three point CBR test is conducted to determine variation of material strength with degree of compaction.

The results of CBR values at 95%MDD for the four source samples are 17.6% Ituha cinder, 25% Ituha pozzolan, 3.2% Mlimanyoka clay and 5.1% Mbalizi gravel. The high CBR value was indicated for Ituha pozzola followed by Ituha cinder. The materials having high plasticity indices which are Mlimanyoka clay and Mbalizi gravel indicated very low CBR values which is because of quick soaking and swelling properties of clayey soils. Figure 4 shows the three points CBR values of the four source materials.

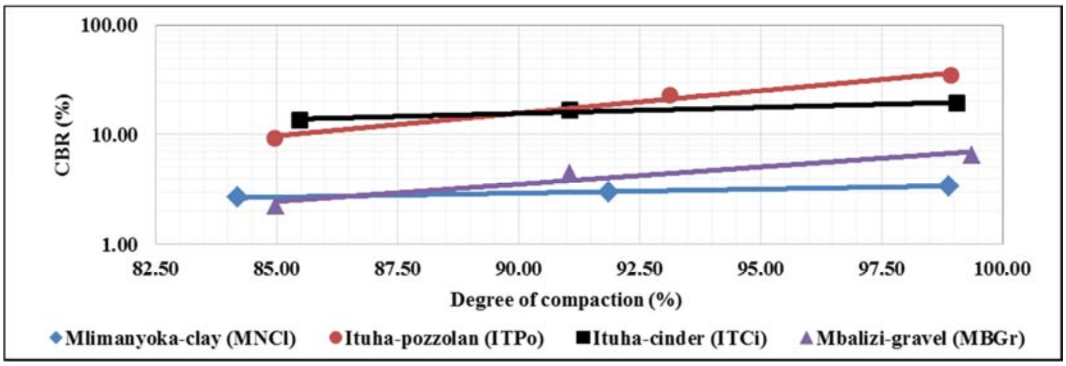

Figure 4. *Three points CBR values of source materials.*

The engineering parameters of the source materials required for construction of surfacing layers of LVRs which are grading coefficients, shrinkage products and CBR values have indicated that all four source materials are not suitable. This is because all materials lack some properties necessary to be suitable for construction of surfacing layers which includes plasticity indices for cinder and gravel materials, lack of course grain particles for clay and pozzolan and high amount of plasticity indices for clay and gravel. Therefore by blending together the materials enhances missing properties from each other to obtain materials which possess required engineering parameters for construction of LVRs.

3.2. Blending Design of Source Materials

The four source materials were blended together into different proportions whereby six new materials were obtained. The blending process were conducted in order to obtain grading coefficient and shrinkage product of the mixture laying within zone E of figure 2. Equation 3 can be used to determine proportions of materials to be blended.

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

Where: PA and PB are proportions of material A and B respectively in decimal, GC_A and GC_B are grading coefficients of material A and B respectively, SP_A and SP_B are the shrinkage products of materials A and B respectively.

The proportional values obtained from equation 3 ranges between 0 and 1, in case the proportional values are outside the range then the materials are not suitable to be blended for construction of surface layer of LVRs. In case there more than two materials to be blended the combined parameters (GC and SP) of the first blended materials are used to blend with other materials.

3.3. Results of Blended Materials

The results for laboratory tested blended materials were sieve analysis, compactions and California bearing ratios. The Atterberg limit data for blended materials were calculated from proportions of source materials.

3.3.1. Characterization and Results of Blended Materials

The characterization of blended materials conducted was particle size analysis tests to determine particle size gradation and percentage passing for sieve sizes 26mm, 4.75mm, 2mm and 0.425mm which are used to compute grading coefficients "GC" and shrinkage product "SP". Table 4 shows the percentage passing to sieve sizes 26mm, 4.75mm, 2mm and 0.425mm and computed grading coefficients and shrinkage products for the blended materials.

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

Source materials	Percentage Passing on Sieve Sizes				Grading Coefficient (GC)	Shrinkage Product (SP)
	26mm	4.75mm	2.00mm	0.425mm		
10MNCl40ITPo50ITCi0MBGr	99.5	83.5	68.4	58.5	22.8	128.3
11MNCl40ITPo39ITCi10MBGr	97.2	82.4	69.6	60.1	20.0	193.9
12MNCl35ITPo40ITCi13MBGr	96.5	81	67.9	58.3	20.4	222.6
13MNCl32ITPo35ITCi20MBGr	94.8	79.6	67.4	58.1	19.3	272.4
14MNCl42ITPo44ITCi0MBGr	99.6	85.1	71.6	62	20.7	179.6
15MNCl25ITPo35ITCi25MBGr	93.6	77.8	65.4	56.1	19.5	324.5

The grading coefficients "GC" and shrinkage products "SP" of all six blended sample materials which are 10MNCl40ITPo50ITCi0MBGr, 11MNCl40ITPo39ITCi10MBGr, 12MNCl35ITPo40ITCi13MBGr, 13MNCl32ITPo35ITCi20MBG, 14MNCl42ITPo44ITCi0MBGr and 15MNCl25ITPo35ITCi25MBGr are within the range of 16 to 34 units and 100 to 365 units respectively. Therefore all six blended sample materials are suitable to be used for construction of surfacing layers of LVRs [1, 15].

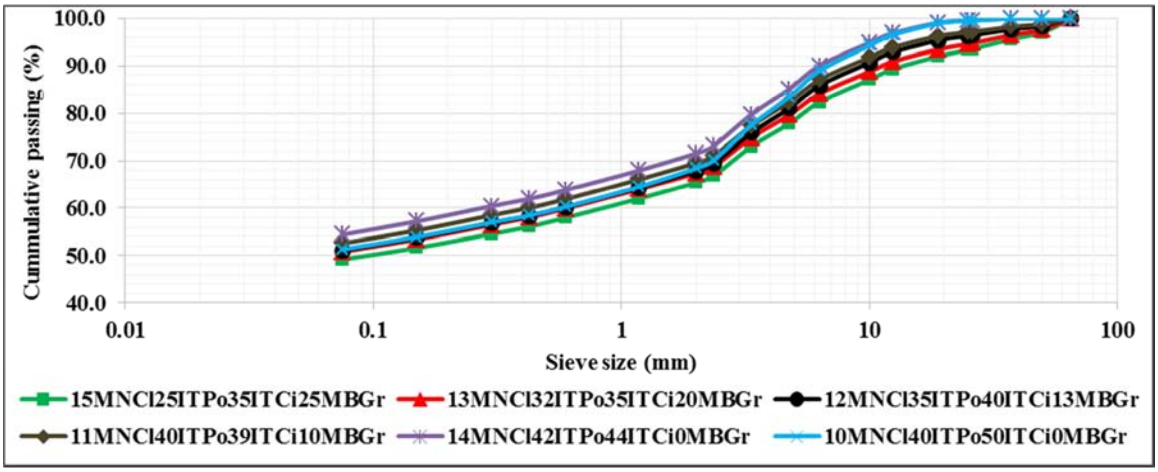

Figure 5. *Particle size distribution curves of blended materials.*

The average particle sizes of six blended sample materials are 3.8mm for 10MNCl40ITPo50ITCi0MBGr, 5.7mm for 11MNCl40ITPo39ITCi10MBGr, 6.3mm for 12MNCl35ITPo40ITCi13MBGr, 7.6mm for 13MNCl32ITPo35ITCi20MBG, 3.7mm for 14MNCl42ITPo44ITCi0MBGr and 8.5mm for 15MNCl25ITPo35ITCi25MBGr. Figure 5 is particle size distribution curves of the six blended sample materials.

In order to ascertain the strength resistance of the blended sample materials, the compaction tests and California bearing ratio tests were conducted for all six blended sample materials.

3.3.2. Compaction and California Bearing Ration (CBR) of Blended Sample Materials

The compaction tests for all six blended materials were conducted using modified BS heavy proctor test to determine maximum dry densities (MDD) and optimum moisture content (OMC) [9]. The results of maximum dry densities and optimum moisture contents obtained for 10MNCl40ITPo50ITCi0MBGr are 1548kg/m^3 and 19.1%, for 11MNCl40ITPo39ITCi10MBGr are 1555kg/m^3 and 19.3%, for 12MNCl35ITPo40ITCi13MBGr are 1590kg/m^3 and 19.8%, for 13MNCl32ITPo35ITCi20MBG are 1672kg/m^3 and 18.4%, for 14MNCl42ITPo44ITCi0MBGr are 1523kg/m^3 and 19.4% and for 15MNCl25ITPo35ITCi25MBGr are 1608kg/m^3 and 20.2% respectively.

The high MDD for the six blended materials are for 13MNCl32ITPo35ITCi20MBG and 15MNCl25ITPo35ITCi25MBGr which are 1672kg/m^3 and 1608kg/m^3 respectively. This is because the mixtures contain substantial amount of Mbalizi gravel and Ituha pozzolan which are heavier than Ituha cinder and Mlimanyoka clay. Figure 6 shows the compaction curves of the six blended sample materials which indicates their maximum dry densities and optimum moisture contents at turning points. Three points California Bearing Ratio (CBR) tests for the six blended materials were conducted using modified BS heavy density to determine CBR values at 95%MDD [9].

The results of CBR values at 95%MDD for the six blended samples are 28% for 10MNCl40ITPo50ITCi0MBGr, 43% for 11MNCl40ITPo39ITCi10MBGr, 56% for 12MNCl35ITPo40ITCi13MBGr, 44% for 13MNCl32ITPo35ITCi20MBG, 39% for 14MNCl42ITPo44ITCi0MBGr and 53% for 15MNCl25ITPo35ITCi25MBGr. Lower CBR values among the six blended sample materials are indicated for 10MNCl40ITPo50ITCi0MBGr and 14MNCl42ITPo44ITCi0MBGr which is because the mixtures did not contain Mbalizi gravel which have larger and strong grain particles to resist plunger shearing force compared to Ituha cinder and Ituha pozzolan materials. Figure 7 shows the three points CBR values of the six blended materials. From the given ranges of grading coefficients "GC", shrinkage products "SP" and California bearing ratio "CBR values" for surfacing layer materials of LVRs it is indicated that all six blended materials are suitable to be used for construction of surfacing layers of LVRs. This is because the GC of the materials are within the range of 16 to 34 units, shrinkage limits are within the range of 100 to 365 units and CBR values are above 15%.

The increased CBR values of blended sample materials is due to interlocking and friction properties of blended samples and addition of clay which act as binder to the coarse grain particles. Regardless of using GC and SP as selection criteria for surfacing layers materials of LVRs, it is important to determine suitable envelopes which should also be used as guidance for selection of the materials. This is because the interlocking and friction resistance of materials are very much enhanced by gradation characteristics of material grain particles.

In order to make use of pozzolanic activities of blended materials, the next study is stabilization with lime and cement to obtain materials suitable for construction of pavement bases for heavy traffic loading.

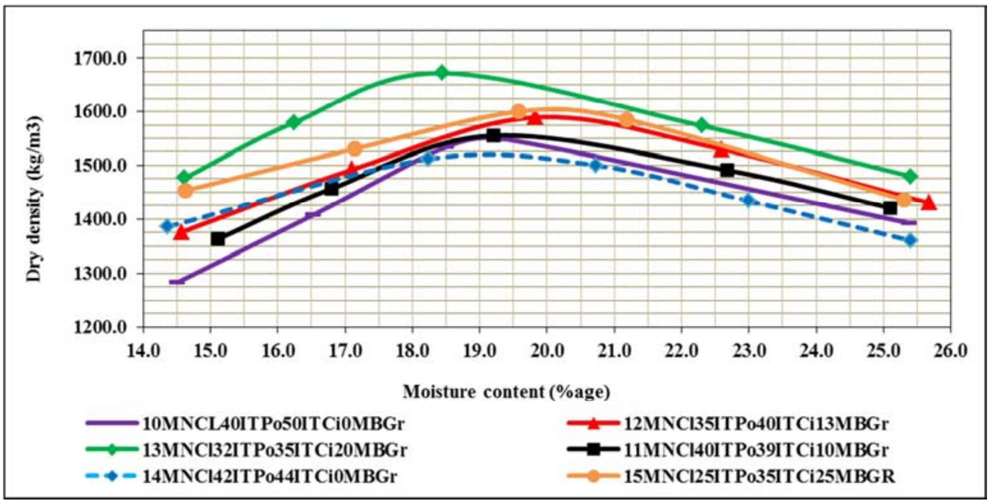

Figure 6. Compaction curves of blended materials.

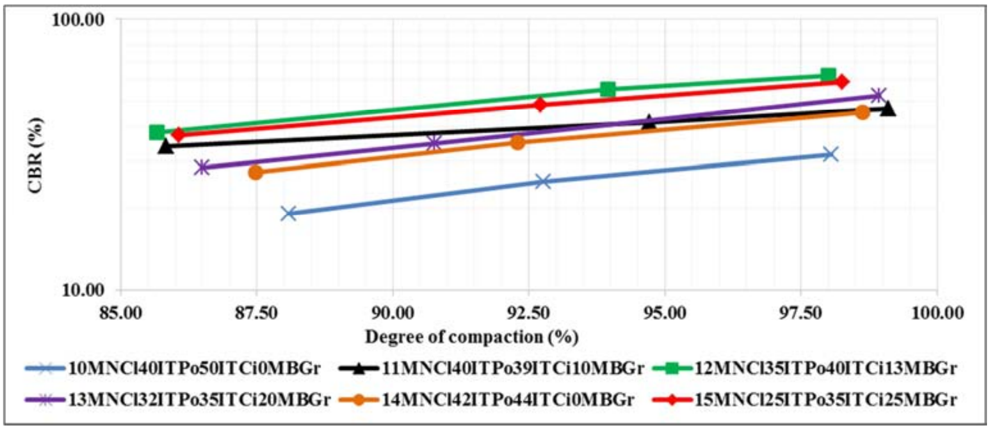

Figure 7. Three points CBR values of blended materials.

4. Conclusions and Recommendations

LVRs in Tanzania contain 75% of the whole road network and serves 80% of the populations. These roads are used to enhance agricultural activities in rural areas which is the major source of income for the people living in rural areas. The construction and maintenance of LVRs in Tanzania is expensive because of scarcity of conventional materials which meets engineering specifications especially in areas with high amount of volcanic materials such as in Mbeya Region. The volcanic materials including volcanic soils and volcanic cinders are considered to be substandard materials since they miss plasticity for binding the materials together. In order to reduce the cost of construction and maintenance of LVRs, it is important to blend volcanic materials with other soils such as clayey soils.

The results from data analysis of four source materials indicated that the grading coefficients (GC) and shrinkage products (SP) are 39.0 and 0.0 units for Ituha cinder, 7.9 and 0.0 units for Ituha pozzolan, 1.4 and 1282.6 units for Mlimanyoka clay and 14.5 and 526.4 units for Mbalizi gravel respectively. The GC and SP for all four source materials are outside range of 16 to 34 units and 100 to 365 units respectively. The California bearing ratio (CBR) values for the four source materials at 95%MDD are 17.6% Ituha cinder, 25% Ituha pozzolan, 3.2% Mlimanyoka clay and 5.1% Mbalizi gravel. The four source materials did not meet engineering requirements to be suitable for construction of surface layers of LVRs, therefore blending of the materials to enhance the missing properties from each other were necessary.

The results for grading coefficients and shrinkage products of six blended materials indicated that all six blended materials are suitable to be used for construction of surfacing layers of LVRs with GC and SP of 22.8 and 128.3 units for 10MNCl40ITPo50ITCi0MBGr, 20 and 193.9 units for 11MNCl40ITPo39ITCi10MBGr, 20.4 and 222.6 units for 12MNCl35ITPo40ITCi13MBGr, 19.3 and 272.4 for 13MNCl32ITPo35ITCi20MBGr, 20.7 and 179.6 for

14MNCl42ITPo44ITCi0MBGr and 19.5 and 324.5 for 15MNCl25ITPo35ITCi25MBGr respectively. The results of California bearing ratios (CRB values) at 95%MDD for six blended materials are above 15% recommended for LVRs which are 28% for 10MNCl40ITPo50ITCi0MBGr, 43% for 11MNCl40ITPo39ITCi10MBGr, 56% for 12MNCl35ITPo40ITCi13MBGr, 44% for 13MNCl32ITPo35ITCi20MBG, 39% for 14MNCl42ITPo44ITCi0MBGr and 53% for 15MNCl25ITPo35ITCi25MBGr.

The increase in CBR values of the blended sample materials is due to interlocking and friction properties of blended samples and addition of clay which act as binder to the coarse grain particles. It is recommended to develop a suitable envelopes for surfacing layer materials for LVRs to be used as guidance for selection of the materials. This is because the interlocking and friction resistance of materials are very much enhanced by gradation characteristics of material grain particles. In order to make use of pozzolanic activities of blended materials, it is also important to stabilize the materials with lime and cement in order to be used for bases of heavy traffic loading. For this study for easy blending process of materials, an equation have been developed, the equation uses grading coefficients (GC) and shrinkage products (SP) of two different materials.

Appendix

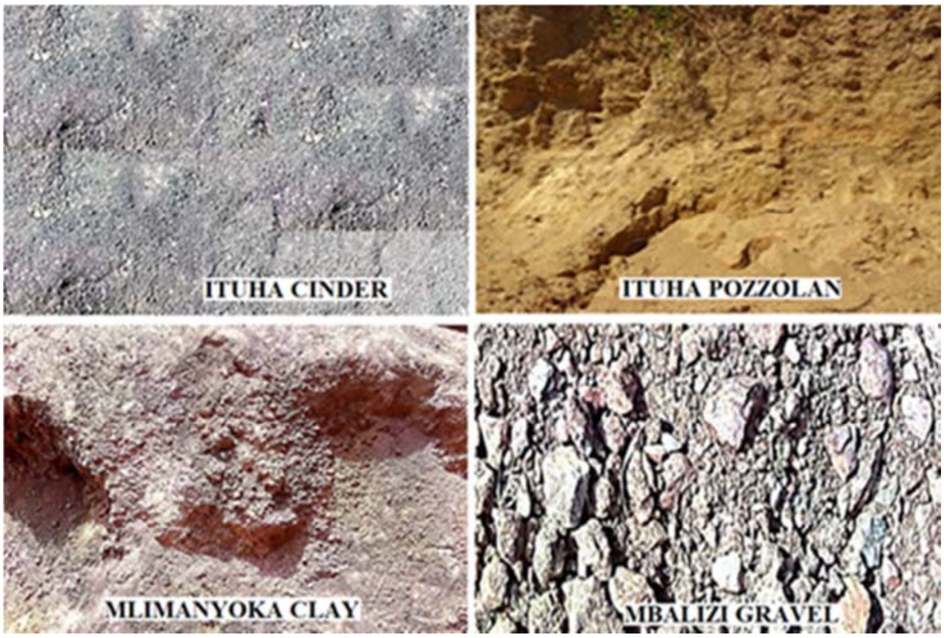

Figure 8. *Photos of source materials.*

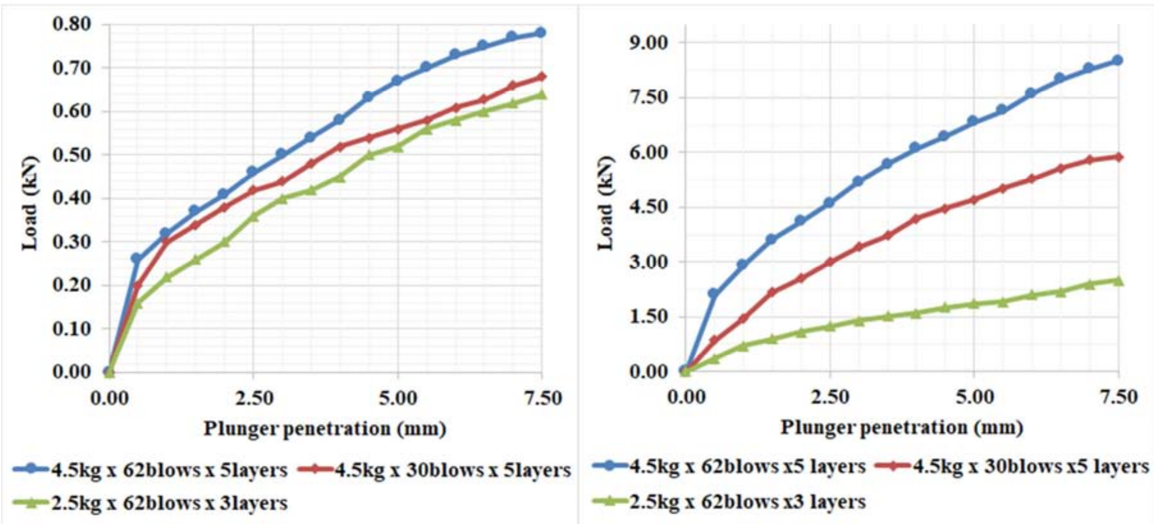

Figure 9. *Penetration resistance of Mlimanyoka-clay (left) and Ituha-pozzolan (right).*

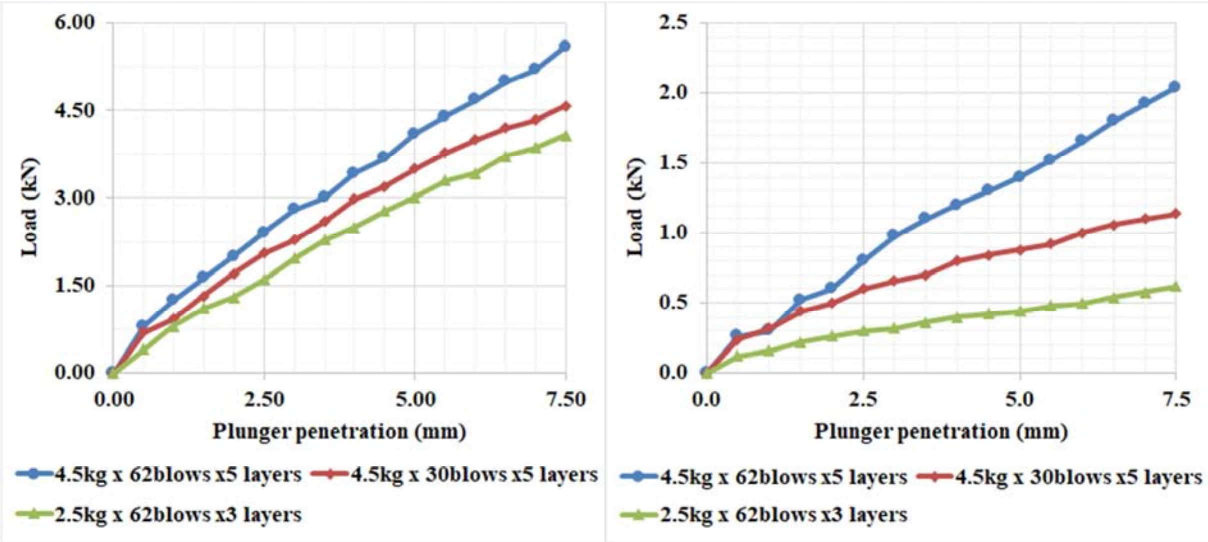

Figure 10. *Penetration resistance of Ituha-cinder (left) and Mbalizi-gravel (right).*

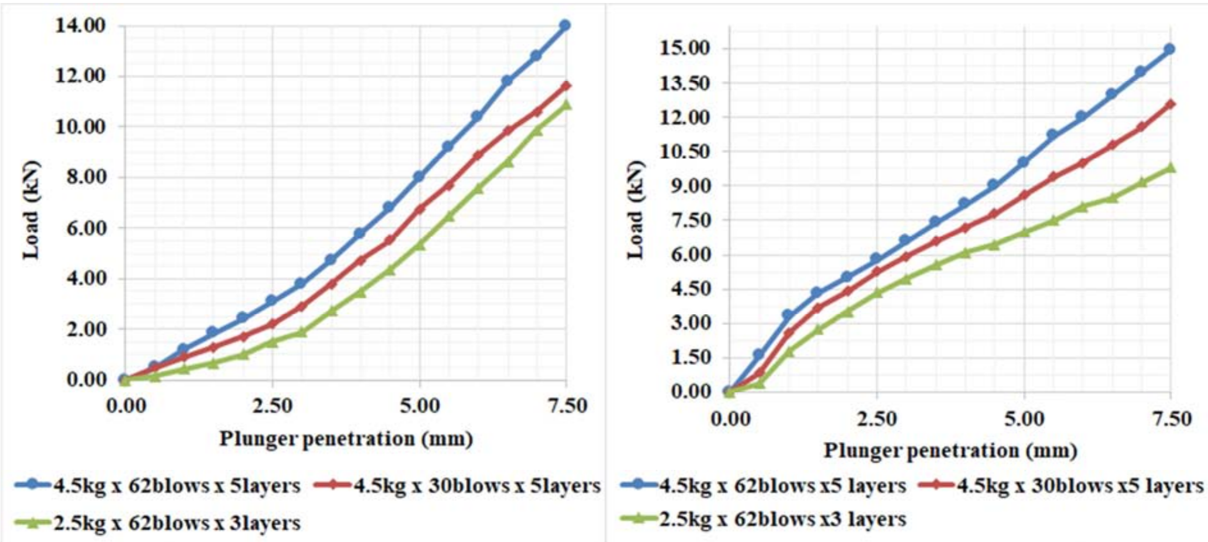

Figure 11. *Penetration resistances of 10MNCl40ITPo50ITCi0MBGr and 11MNCl40ITPo39ITCi10MBGr curves.*

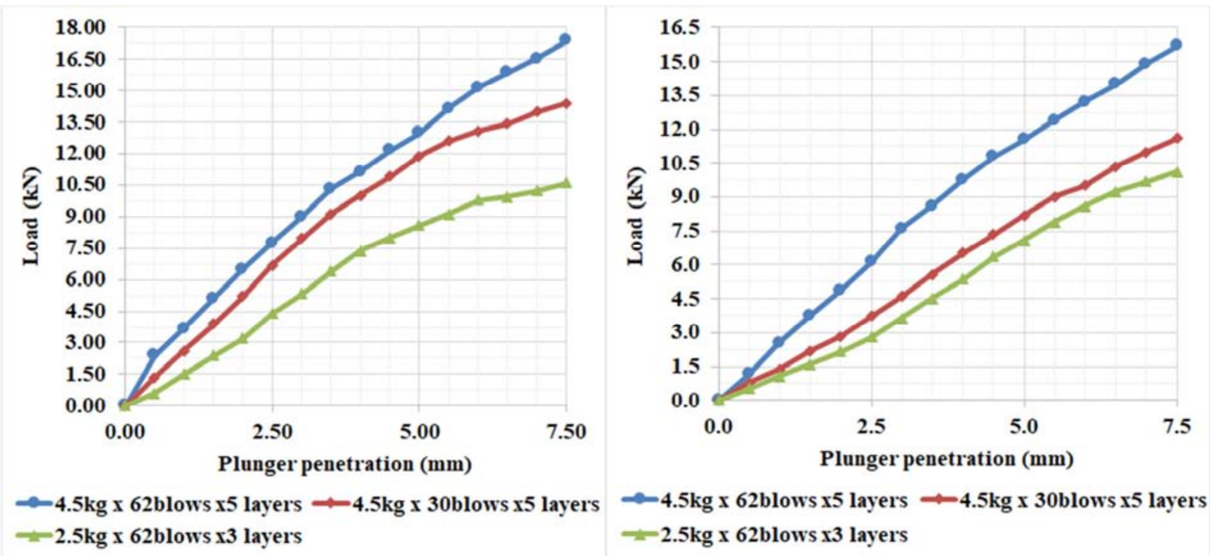

Figure 12. *Penetration resistances of 12MNCl35ITPo40ITCi13MBGr and 13MNCl32ITPo35ITCi20MBGr curves.*

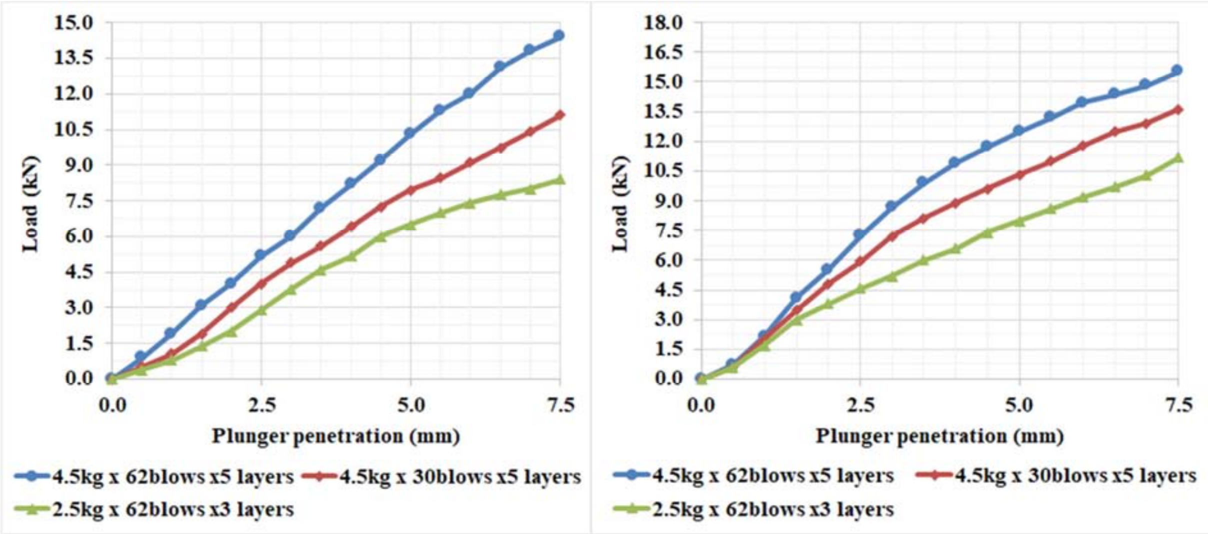

Figure 13. *Penetration resistances of 14MNCl42ITPo44ITCi0MBGr (left) and 15MNCl25ITPo35ITCi25MBGr.*

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