Feasibility of Lightweight Aggregate Concrete for Structural and non-Structural works in Tanzania

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ABSTRACT: There has been serious land degradation in Tanzania due to extensive exploitation of granite aggregates even in areas where there is plenty of natural lightweight aggregates. Many Engineers have resorted to using normal weight aggregates in construction not only due to the feeling that lightweight aggregates (LWA) are too weak for the purpose but also mainly due to lack of knowledge of the design procedures for lightweight aggregate concrete (LWAC). Structures made of normal weight aggregates have higher dead loads which demand reduced span lengths, deeper structural members, more reinforcement and increased foundation area when compared to those made of LWAC. In Tanzania there are major deposits of LWA in areas of previous volcanic eruptions namely Kilimanjaro, Mbeya and Arusha and these remain largely unexploited. Research was done to investigate the feasibility of using scoria and pumice aggregates in structural lightweight concrete. The aggregates were obtained from Kilimanjaro and Mbeya respectively. A mix design for grade 20 concrete was performed for both aggregates. It was found out that it was possible to use the scoria aggregates for structural concrete but not the pumice without mineral additives or chemical admixtures. Using pumice aggregates without any additives, the strengths obtained were less than 17 MPa which is the minimum strength acceptable for structural LWAC. It was concluded that the use of scoria aggregates for structural LWAC was feasible and that the pumice aggregates could be used for non-structural LWAC. Further research is required to find alternative deposits of pumice with better strengths for use in structural LWAC as the strengths of these aggregates vary from place to place and even within the same locality. Structural and Construction Engineers in Tanzania are now in a position to design and use LWAC as the design procedures have now been elaborated. The use of light weight aggregates especially in areas where these deposits are present will reduce the current costs of transport of normal weight aggregates from long distances and this will also protect the environment.

1 INTRODUCTION

Lightweight concrete (LWC) is defined as the concrete of substantially lower unit weight than that made of gravel or normal weight crushed aggregates. The dry densities are normally in the range of 800 to 2000 kg/m^3 (Schlaich & Zareef, 2008). In practice, designation of lightweight concrete is according to standardized strength and density classes (Chandra et al., 2002). Lightweight concretes having dry densities below 800 kg/m^3 are defined as Infra-lightweight concretes. Lightweight concrete is produced by either using lightweight aggregates or by formation of voids in concrete by omitting sand or by formation of voids in cement by addition of substances causing foam. There are three categories of LWC, namely structural LWC, low density LWC and moderate strength LWC (Neville & Brooke, 2005). According to NRMCA (2003), structural LWC has an in place density of between 1440 kg/m^3 and 1840 kg/m^3. Clarke (2005) defines structural LWC as having densities in the range of 1200 kg/m^3 to 2000 kg/m^3. Normal density concretes range from 2200 kg/m3 to 2600 kg/m^3 depending on the type of aggregates used (Neville & Brooke, 2005). According to the above literature, structural LWC should have a minimum compressive strength of 17 MPa. LWC is manufactured by combination of fine and course lightweight aggregates or course lightweight aggregates with normal weight fine aggregates. Complete replacement of normal weight aggregates with lightweight aggregates reduces the air dry density to about a half that of normal weight concrete (Clarke, 2005; NRMCA, 2003). Neville & Brooke (2005) defines three classes of LWC which can be made available according to their method of production: (i) No fines concrete obtained by omitting the finer fraction of normal weight or lightweight aggre-

gates to create air filled voids, (ii) Aerated concrete produced by inclusion of air bubbles in cement paste or cement mortar matrix to form a cellular structure. This contains 30 – 50 % voids and (iii) Lightweight aggregate concrete obtained by replacing either wholly or partially normal weight aggregates in a concrete mix with lightweight aggregates of low apparent specific gravity (porous aggregates containing large proportion of voids). This last type is the subject of the present investigation where all course aggregates were replaced with lightweight aggregates of pumice or scoria to obtain what we refer to as light weight aggregate concrete (LWAC). LWC does not provide only lighter structures but also structures with better insulation against heat and sound and such structures are more resistant to earthquakes.

2 OBJECTIVES OF THE INVESTIGATIONS

The objective of the investigations was to find out whether pumice and scoria aggregates found in vast quantities in SW (Mbeya) and NE (Kilimanjaro) of Tanzania respectively were suitable for producing structural light weight concrete. Engineers in Tanzania prescribe the use of normal weight aggregates in these areas despite the fact that normal weight aggregates are very expensive as they have to be hauled from very long distances. One of the reasons that many engineers do not use these LWC aggregates is due to lack of knowledge of the mix design procedures for LWAC.

3 MATERIALS AND METHODS

Pumice and scoria aggregates were sampled from Mbeya and Kilimanjaro respectively (Figure 1).



Figure 1. Scoria (L) and Pumice(R) aggregates used

The cement used was Portland limestone cement CEM II/A-L/32.5R and was tested to conform to BS EN 197-1-2000. Natural sand was tested for its gradation (Figure 2) according to BS 812-103.1:1985. Volumetric sieve analysis according to TxDOT (2008) was performed on the scoria and pumice aggregates (Figures 3 and 4). The results show that about 60% and 70% of the scoria and pumice aggregates respectively lie between 4.75 mm and 37.5 mm.

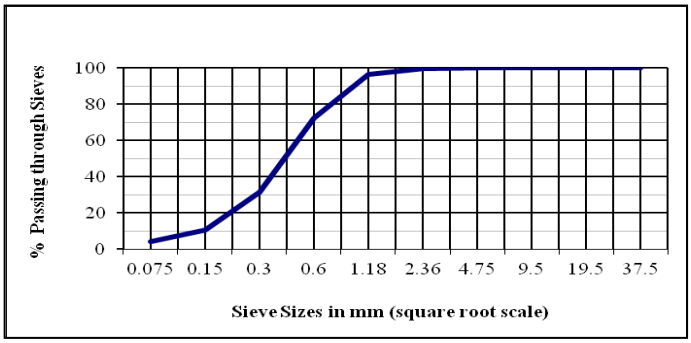


Figure 2. Sieve analysis of natural sand

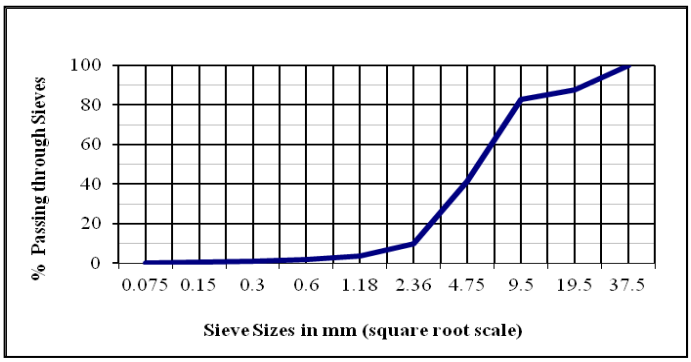


Figure 3. Volumetric analysis of scoria aggregates

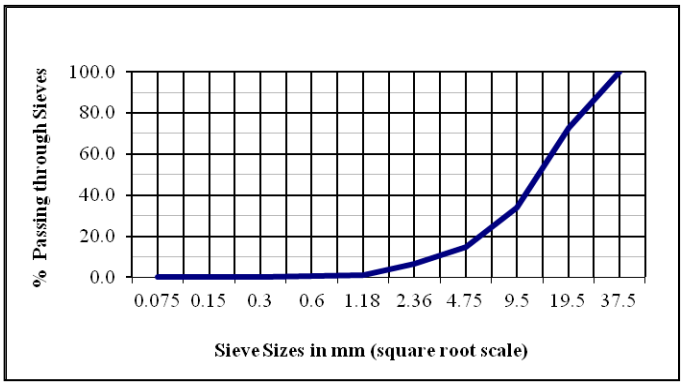


Figure 4. Volumetric analysis of pumice aggregates

The ten percent fines value test was done for scoria and pumice aggregates according to BS 812 part 111:1990 and the values obtained were 89 kN and 52 kN respectively. Table 1 shows the physical properties of the aggregates used.

Table 1. Physical properties of LWA used

Aggregate type	Units	Scoria	Pumice	Sand
Bulk density	kg/m^3	882	411	1422
SSD Density	kg/m^3	1826	1087	-
Oven-dry Density	kg/m^3	1592	537	-
Specific Gravity	kg/m^3	1.754	0.886	2.625
Particle Density	kg/m^3	1754	886	2625
Agg. Crushing Value	(%)	47	-	-
10% Fines Value	(kN)	89	52	-

4 MIX DESIGN PROCEDURE FOR LIGHT WEIGHT AGGREGATE CONCRETE (LWAC)

The main emphasis in the design of LWAC is that the density and the strength of the LWA are related to the density and strength of the concrete.

4.1 *Determination of the Mean Compressive Strength of Concrete*

The compressive strength should satisfy the following conditions:

$$f_m = f_{cu} + \lambda S_n \quad (1)$$

where f_m = mean compressive strength; f_{cu} = specified characteristic strength; λ = statistical factor dependent of the acceptable probability of failure; and S_n = standard deviation of the distribution. The coefficient of variation is approximately 5 – 10 % for the strength and 3 – 5 % for the density (Chandra & Brooke, 2002)

4.2 *The strength of the LWA Particles*

The recommendation is to design the concrete mortar with a compressive strength double that of the strength of the lightweight aggregate. The mean compressive strength of the lightweight aggregate is calculated using the formula:

$$f_{la} = a \cdot 10^{b\rho/1000} \quad (2)$$

where a and b are coefficients according to Table 2 and ρ is the particle density in kg/m^3. For all types of LWA, natural or factory produced, there are different relationships between the strength of the LWA and the particle density. There are special methods the particle strength of the aggregate. Because the particles interact with the surrounding matrix, the cement paste or mortar, the method is based on estimating the strength of the concrete. The results are then used to evaluate coefficients a and b in equation (2).

Table 2. Coefficients a and b in Equation (2) (Chandra & Leif, 2002)

Aggregate No.	*a*	*b*
1	1.52	1.14 (1.08, 1.03)
2	1.12	1.22 (1.16, 1.11)
3	1.00	1.25 (1.15, 1.14)
4	0.89	1.28 (1.22, 1.17)

In parenthesis the value of b is for 5 and 10% water content in the aggregate. The value of b is not or is marginally influenced by the water content. Aggregate no. 3 is for the bulk density of 300 kg/m^3. The LWA is some type of high quality sintered clay. Other LWA may have other values and shall be provided after the test.

The relationships among the strength of mortar, the strength of the LWA, the strength of the concrete, and the volume of the mortar or volume of the LWA are calculated using:

$$\log f_{con} = v_{la} \cdot \log f_{la} + v_M \cdot \log f_M \quad (3a)$$

or

$$\log f_M = \frac{\log f_{con} - v_{la} \cdot \log f_{la}}{1 - v_{la}} \quad (3b)$$

where f_{con} = strength of concrete; f_M = strength of mortar; f_{la} = strength of LWA; v_{la} = volume of the LWA particles; and v_M = volume of mortar.

4.3 *The Compressive Strength of Mortar*

The compressive strength of mortar can be calculated from equation (4). Here natural sand and ordinary Portland cement are assumed to be used, and the specimens for mortar testing are the same type and size as used for the testing of concrete.

$$f_M = A \cdot 10^{-B(W/C)} \quad (4)$$

where A and B are experimentally evaluated coefficients. With A=140 and B=0.87 (ordinary Portland cement after 28 days and W/C or W/binder > 0.30), the compressive strength is:

$$f_M = 140 \cdot 10^{-0.87(W/C)} \quad \text{or}$$

$$W/C = \log\left(\frac{140}{f_M}\right) / 0.87 \quad (5a)$$

When W/C > 0.20 and < 0.25, the following formula is is used:

$$f_M = 160 \cdot 10^{-0.87(W/C)} \quad (5b)$$

When W/C is between 0.25 and 0.30, A is to be interpolated. According to accepted definition, the water/cement ratio is: $W/C = W \cdot 10^3 / C$ where W is the water content in m^3/m^3 and C is the cement content in kg/m^3. The formulae are valid for natural sand, not lightweight sand, and for water/cement ratio less than 0.8. (Chandra & Leif, 2002).

4.4 *The Volume of Cement Paste*

The volume of cement paste or binder in concrete should adhere to the principle of a constant paste-aggregate volume and should be about 30% of the volume of concrete. The volume of cement paste depends on many factors, for example, the type and shape of aggregate, consistency, stability of the con-

crete mixture, the strength of the mortar or concrete and water absorption of the LWA. According to experience even from normal weight concretes, the volume of the cement paste or binder may be in the range of 30 ± 2%. (Chandra & Leif, 2002).

4.5 *Cement Content*

The cement content is calculated using the formula:

$$C = \frac{1000 \times \nu_p}{0.31 + W/C} \text{ kg/m}^3 \quad (6)$$

where ν_p = volume of cement paste in concrete.

4.6 *Volume of Sand*

The volume of sand is calculated from the formula

$$\nu_s = 1 - \left(\nu_p + \nu_{la} + \nu_{air}\right) \quad (7)$$

where ν_{la} = volume of LWA; and ν_{air} = volume of air in the concrete. Normally, the air volume is 1.5-2% of the volume of concrete.

4.7 *The Bulk Density of the Concrete*

The density of the concrete can be obtained by adding all the amounts of the ingredients in 1 m^3 of compacted concrete.

5 MIX DESIGN CALCULATIONS

The mix proportioning of the LWAC using the scoria and pumice aggregates was based on estimating first the coefficients a and b in equation (2) by interpolating the values shown on Table 2. The coefficients were then recalculated from trial mix design strength test results using Equation (3a) The recalculated coefficients are plotted on Figures 5 and 6. Three trial mixes (Trial 1, Trial 2 & Trial 3) were then prepared each with the pumice and the scoria aggregates. Table 3 and Table 4 show the design parameters and the calculations respectively.

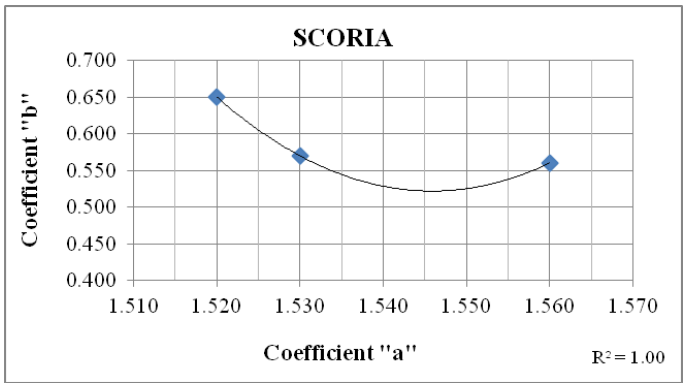


Figure 5. Strength coefficients for scoria aggregates

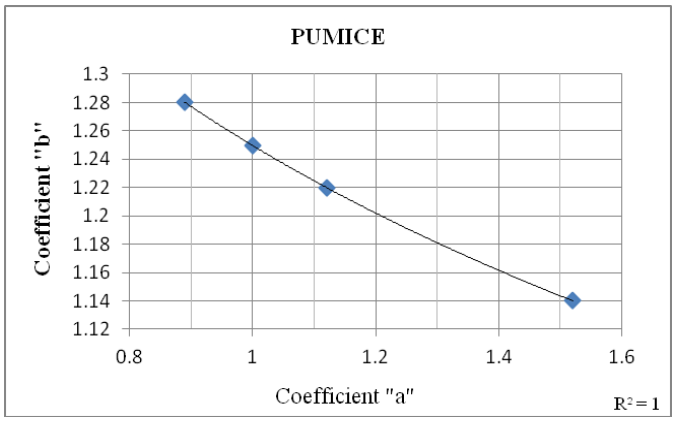


Figure 6. Strength coefficients for pumice aggregates

Confidence factor, $\lambda = 1.64$. Standard deviation, $S_n = 8.5$. Characteristic strength, $f_{cu} = 20$ MPa. Mean Compressive strength, $f_m = f_{cu} + \lambda S_n = 33.94$ MPa

Table 3. Mix Design Parameters

		Scoria	Pumice	Sand	Cement
Bulk density(kg/m^3)		882	411.0	1422	1670
Particle density (kg/m^3)		1760	869	2620	3150
Water Absorption (60 min.) (%)		0.8	5.0		
Coefficient "a"	Trial 1	1.520	1.0000		
	Trial 2	1.530	1.0500		
	Trial 3	1.560	1.0000		
Coefficient "b"	Trial 1	0.650	1.2490		
	Trial 2	0.57	1.2363		
	Trial 3	0.56	1.2242		

Table 4. Calculations

Mean strength f_m		33.93 MPa	
Strength of LWA (MPa)			
		Scoria	**Pumice**
$f_{la} = a \cdot 10^{b\rho/1000}$	Trial 1	21.18	12.17
	Trial 2	15.41	12.46
	Trial 3	15.09	12.74
Strength of mortar (MPa)			
Equation 3(b)	Trial 1	43.75	58.95
	Trial 2	51.92	58.22
	Trial 3	52.51	57.52
Water cement ratio for OPC			
Equation 5(a)	Trial 1	0.58	0.43
	Trial 2	0.50	0.44
	Trial 3	0.49	0.44
Volume of cement paste=0.35			
Cement content (kg/m^3)			
Equation 6	Trial 1	393.00	471.86
	Trial 2	434.68	467.89
	Trial 3	437.76	464.17

Table 4. Calculations (continued)

		Scoria	Pumice
Water Content (kg/m^3)			
W = C x (W/C)	Trial 1	228.17	203.72
	Trial 2	215.25	204.95
	Trial 3	214.29	206.11
Slump between 25mm to 100mm O.K. Air Content 2.00%			
Effective Water (kg/m^3)			
		Scoria	**Pumice**
	Trial 1	208.17	183.72
	Trial 2	195.25	184.95
	Trial 3	194.29	186.11
Volume of natural sand (m^3)			
Equation 7	Trial 1	0.28	0.28
	Trial 2	0.28	0.28
	Trial 3	0.28	0.28
Weight of natural sand (kg/m^3)		733.6	733.6
Bulk volume of natural sand (m^3)		0.52	0.52
Weight of LWA (kg) : $W_{la} = V_{la} \times \rho_g$		616.00	304.15
Bulk volume of LWA: $V_{la} = V_{la} \times \rho_g/\rho_b$		0.70	0.74
Water absorption $W_{abs}=W_{la} \times w_{abs}$		4.93	15.21
Water to be added (kg)			
	Trial 1	213.10	198.93
	Trial 2	200.18	200.16
	Trial 3	199.22	201.31

Ingredients per cubic meter

Scoria	**Trial Mix S1**		**Trial Mix S2**		**Trial Mix S3**	
	kg	m^3	kg	m^3	kg	m^3
LWA	616	0.352	616	0.352	616	0.352
Natural sand	734	0.282	734	0.282	734	0.282
Portland cement	393	0.125	435	0.138	438	0.139
Water	213	0.213	200	0.200	199	0.199
Air		0.020		0.020		0.020
Density of fresh LWC	1956 (kg/m^3)		1984(kg/m^3)		1989(kg/m^3)	

Pumice	**Trial Mix P1**		**Trial Mix P2**		**Trial Mix P3**	
	kg	m^3	kg	m^3	kg	m^3
LWA	304	0.343	304	0.343	304	0.043
Natural sand	734	0.282	734	0.282	734	0.282
Portland cement	472	0.150	468	0.150	464	0.150
Water	199	0.199	200	0.200	201	0.201
Air		0.020		0.02		0.020
Density of fresh LWC	1709(kg/m^3)		1706(kg/m^3)		1703(kg/m^3)	

6 TEST RESULTS

6.1 *Tests on fresh concrete*

The workability and density of the LWAC were measured according to BS 206-1:2000 and the air content was according to BE 96-3942/R4 (1999). The results are shown on Table 5.

Table 5. Tests on fresh concrete

Aggregate type	**Scoria**			**Pumice**		
Mix ID Number	S1	S2	S3	P1	P2	P3
Slump (mm)	30.0	30.0	32.0	30.0	37.0	35.0
Air Content (%)	4.8	4.2	4.0	7.8	7.6	7.0
Density (kg/m^3)	1833	1828	1816	1475	1480	1466

6.2 *Tests on hardened concrete*

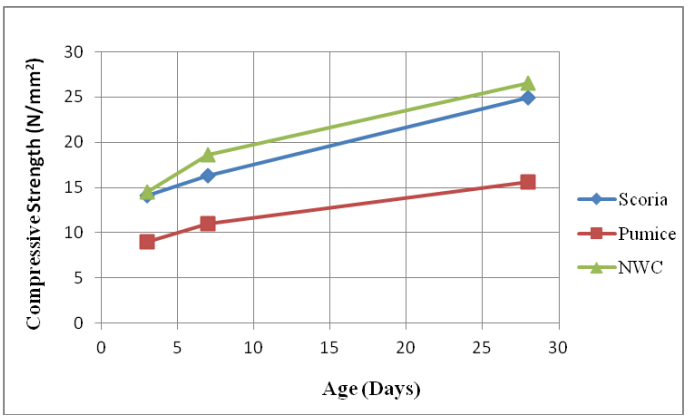
The test results on densities and compressive strength of the hardened concrete is shown on Table 6. Figure 7 shows the failure mode of the concrete cubes after the compressive strength tests and they clearly show that failure was initiated by failure of the aggregates which were weaker than the mortar. The development of strength of the concretes with age is shown on Figure 8.

Table 6. Tests on hardened concrete

Mix No.	Cement content (kg/m^3)	Density at 28 days (kg/m^3)	Strength (N/mm^2)			Coefficient of strength of LWA	
			3d	7d	28d	α	b
S1	393	1990	12.4	14.4	24.3	1.52	0.65
S2	435	2020	15.8	17.9	25.0	1.53	0.57
S3	438	2020	14.0	16.5	25.4	1.56	0.56
Ave.	**422.3**		**14.1**	**16.3**	**24.9**		
P1	472	1838	9.4	12.4	16.7	1.00	1.25
P2	468	1813	9.0	10.5	15.2	1.05	1.24
P3	464	1830	8.6	10.1	14.9	1.10	1.22
Ave.	**468**		**9.0**	**11.0**	**15.6**		



Figure 7. Modes of failure of the scoria (left) and pumice (right) concrete cubes



NWC = normal weight concrete

Figure 8. Relationship between compressive strength and age

7 DISCUSSION OF RESULTS

The tests on fresh concrete for both the scoria and pumice concretes gave slump values between 25mm and 100mm as expected indicating medium workability. The air content was, however, higher than the 2% assumed in the design. The densities of the fresh concretes were also a bit lower than the design values (Tables 4 & 5). This might have partly been due to insufficient compaction of the concrete but it has to be mentioned here that some of the formulae used in the design are empirical in nature and these variations are not unexpected. Tests on the hardened concrete (Table 6) showed that the dry densities of the LWAC produced were actually in the range of 1200 to 2000kg/m^3 as defined by Clarke (2005). The design characteristic strength of 20 MPa at 28days was reached with the scoria aggregates but not with the pumice. The average strength reached with pumice aggregates was 15.6 MPa which was lower than the 17 MPa recommended for structural LWC. Developing a concrete of grade 20 with pumice went beyond the capability of the pumice aggregate which was weaker than the scoria. This was actually observed in the modes of failure of the tested concrete cubes (Figure 7) where it was found out that in both cases it was the aggregates that actually failed first in tension. The mortar was designed to be of a strength greater than that of the lightweight aggregate as recommended (Table 4). Table 6 shows that using LWAC the demand for cement/m^3 is higher than with normal concrete using normal aggregates. This additional cost is offset by the additional costs which would be incurred by transporting normal aggregates from longer distances to these locations.

8 CONCLUSIONS AND RECOMMENDATIONS

It can be concluded from these investigations that the scoria aggregates are suitable for structural concrete and the pumice aggregates for non-structural purposes. Non-structural concrete is employed in the construction of non-load bearing elements, roof, floor and wall insulation and production of self curing concrete. In a separate study by the second author, it was established that the pumice in the present study can also be used in the production of concrete suitable building blocks. It was also noted from literature that mineral additives and chemical admixtures such as silica fume, ground blast furnace slag, fly ash, super-plasticizers etc. are used in LWA concrete mixes to improve LWC strengths. This can also be applied with these aggregates to get better concrete strengths. There is a need of characterization of the lightweight aggregates that are present in vast amounts in Tanzania so that they can be better utilized. There is also a need to disseminate the knowledge of the use of lightweight aggregate concrete to engineers in Tanzania so that they can start utilizing this material in construction.

9 REFERENCES

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