FEASIBILITY OF PRODUCING LIGHTWEIGHT CONCRETE USING INDIGENOUS MATERIALS WITHOUT AUTOCLAVING

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ABSTRACT

This research shows the feasibility and sequential approach for producing lightweight concrete without autoclaving using indigenous ingredients and appropriate technology of Bangladesh. Ingredients were mixed chronologically using trial-and-error method to reduce unit weight. Specific volume principle was utilized to observe the effect of inclusion of cement, water, sand, lime and aluminium in the mixture to achieve the goal. Molds were used to accommodate volumetric expansion of mixture. Both 50 mm and 150 mm cubic specimens were prepared for tests. Density and compressive strength were determined for specimens. Absorption capacity and thermal conductivity were also determined to get the product performance. From the results, it was seen that density and compressive decreased with increased water-cement ratio. Volumetric expansion was high for higher volume surface ratio. Finally, lightweight concrete with density, compressive strength and thermal conductivity within range of 700-1000 kg/m3, 0.5-2.0 MPa and 0.2-0.5 W/m-k respectively was produced.

KEY WORDS: *Volumetric expansion, Lightweight concrete, Water-cement ratio, Mix design.*

1.0 INTRODUCTION

Diverse use of lightweight concrete is well recognized all over the world. NRMCA (2003) suggested that the best suitable option to reduce dead load of a structure lie within the deduction of self-weight of concrete, which eventually reduces size of structural elements. Studies (Haug et al. 1996; Ahmed et al. 2004; Lijiu et al. 2005; Lo et al. 2006; Arisoy et al. 2008; Mouli et al. 2008) showed that lightweight concrete has wide opportunity not just as structural material but also other decorative elements due to performance and durability. Decoration elements such as timber, plastics are inadequate and their uses are concerned with adverse impacts on environment especially for a developing country like Bangladesh. Lightweight concrete is generally produced by two means (ACI 523.3R-93, ACI 213R-03). One is cellular concretes referred to lightweight concretes, which contain stable air or gas cells uniformly distributed in the mixture. Cellular concretes commonly include natural or manufactured sand aggregate. In other types, aggregates may be added; for example, manufactured lightweight aggregates such as expanded clay, shale, slate, sintered fly ash, perlite, and vermiculite as well as natural lightweight aggregates such as pumice, scoria, or tuff. Air cells can be intruded from outside through rigorous mixing or by chemically by mean of any reaction producing air bubbles. Due to unavailability of lightweight aggregate in Bangladesh, lightweight concrete was produced using chemically induced void in cement mortar matrix in this study. This research is aimed to observe the effect of volume-surface ratio and aluminium content on volumetric expansion of lightweight concrete.

2.0 RESEARCH SIGNIFICANCE

Lightweight concrete and its future prospects are well established but rigorous study has not been done yet on this field. This study is the pioneer feasibility approach for producing lightweight concrete in Bangladesh. This research enumerates possible indigenous materials those can be incorporated in producing lighter concrete for various decorative, infill and partition related constructions. This study will open new approach for improved large-scale super lightweight concrete production. Authors believe that as first of its kind in Bangladesh, the outcome provides ahead start for the next researchers interested in this field.

3.0 EXPERIMENTAL PROGRAM

GENERAL APPROACH

First phase of this research focused on the feasibility of reducing unit weight of concrete. "Trial and Error" method was utilized for the production of lightweight mortar from locally available materials such as Cement, Local sand, Lime, Aluminium Powder. Specific weight principle was utilized to see the contribution of ingredients in mixture. Although large amount of void was to be inserted in the matrix, specific weight basis analysis approach was applied for the research.

$$\sum \frac{W_i}{S_i} = 1000 \quad \text{......(1)}$$

Here
W_i = Weight of i materials in kg
S_i = Specific Gravity of i material

Next approach was to improvise production technique to optimize the goal. Effect of mold size on volumetric expansion of produced concrete was also observed.

MIX PROPORTIONS

Five mixture bands were made to compare the effect of inclusion of ingredients to produce lightweight concrete. First band; B-1 was prepared to observe the void intrusion by aluminium in the cement matrix. Cement content and water content were 1071 and 643 kg/m3 respectively along with varied cement-aluminium ratio by weight. Next band of mixture; B-2 was selected to visualize initial condition of mortar mixture without compaction and expansive agent for varying water-cement ratio from 0.40 to 0.85. Constant sand-cement ratio 1.5 was used in this research as this ratio is widely used in normal weight concrete. Mix proportion B-3 and B-4 were implemented to observe the effect of aluminium and lime respectively. To accommodate volumetric expansion, 150 mm cube mold was used in mix band; B-5 and B-6 having cement-aluminium ratio 100 and 50 respectively. B-4 and B-6 were containing identical mix proportion with different mold capacity (50 mm and 150 mm cube respectively). These are reported in Table 1. Water-cement ratio for the mix bands was not identical due to trial and error approach. On affirmation test results of a band another band was formed and tested. Absorption capacity and thermal conductivity were also determined to obtain product properties.

TEST SPECIMEN

Mixtures were prepared in steel bowls mixing the ingredients. Specimens were cast in 50 mm steel cube ($Volume/Surface = \frac{50x50x50}{4x50x50} = 12.5$). No vibration was used on low viscous mixture to avoid segregation and uniform distribution of bubbles. Side and bottom joints of moulds were sealed with grease to resist water leakage. Samples were removed from mould after 24 hours and cut to 50 mm cubes. Figure 1 referred. Samples were allowed to cure for 28 days. Density and compressive strength were determined for samples. Same procedure was applied for 150 mm cube ($Volume/Surface = \frac{150x150x150}{4x150x150} = 37.5$) during second phase of the research, thereby effect of volume-surface ratio on volumetric expansion was observed. Absorption capacity and thermal conductivity of selected samples was determined to get property trend. Samples were cut to size required for thermal conductivity test by apparatus of Lee's method (Young 2006).

Figure 1: Volumetric expansion in cube sample and voids distribution in mortar matrix

4.0 MATERIALS

As prime binder in this investigation commonly available cement CEM II (BDS 197-1); Portland Composite Cement (PCC) with specific gravity 3.0 was used. Cement was tested for strength conforming ASTM C 109 and fineness conforming ASTM C 204. Average compressive strength of PCC for 3-days, 7-days and 28-days were 17, 21 and 30 MPa, respectively. Test by Blaine's apparatus suggests PCC having fineness 330 m^2/kg. Most commonly available sand of Bangladesh is Savar sand. Basic physical properties were determined for Savar sand used for this research. Unit weight was measured as per ASTM C 29, specific gravity and absorption capacity were determined conforming ASTM C 128 and sieve analysis was conducted conforming ASTM C 136. Specific gravity (OD), Specific gravity (SSD), Apparent specific gravity, Absorption capacity, Unit weight (loose), Unit weight (Compact) and Fineness modulus were found 2.14, 2.33, 2.63, 8.67%, 1346 kg/m^3, 1484 kg/m^3 and 1.02 respectively. For this research, lime is used as an expansive agent for its violent volumetric slaking in presence of water (Aziz 1995). Unslaked local lime was finely ground to get fine powder. Specific gravity of lime was 2.40. To ensure uniform fineness, ground lime was screened through #200 ASTM sieve. Aluminium powder was the prime void intruder in this research. Pure aluminium reacts with water as Equation 2 to produce Hydrogen gas (Haque and Alam 2007, Rosa 2009).

$$2Al + 6H_2O = 2Al(OH)_3 + 3H_2(\uparrow) \quad ....(2)$$

Aluminium powder containing 99.9% assay was used to get desired void intrusion.

5.0 EXPERIMENTAL RESULTS

Materials identified as potential ingredients of aircrete were not enough to produce required void inside concrete matrix. Thus a bubble intruder; aluminium powder was introduced. Figure 2 shows effect of aluminium content on strength and density. To get a comparison, cement content and water content were kept fixed as 1071 kg/m^3 and 643 kg/m^3, respectively. Results show that density decreases with increased aluminium content but strength declined. However, this study was done in aim of identifying aluminium content to get desired void intrusion. The aluminium content was selected as 1 gm of aluminium for 50 gm of cement for B-2, B-3, B-4 and B-6. This content was conservative but consideration was kept in mind that sand and other fillers; if required would have to be inserted yet. Cement alone is a very expensive material and should be associated with other filler like sand or coarse aggregate. As filler, Savar sand was used in this research. Table 1 represents mix proportions and corresponding test results. Compressive strength and density of tested specimens are shown in Figure 3 and Figure 4 respectively. Variation of strength and density are plotted for mix bands B-2, B-3, B-4, B-5 and B-6 with respect to water-cement ratio.

Mix Design	S/C	C/L	W/C	C/A	Compressive Strength[a]	Density[b]	Mold Size
B-1	-	-	0.60	500	4.98	1066	50 mm
				333	4.65	1065	
				250	4.36	1041	
				200	3.97	1035	
				125	2.84	953	
				100	2.07	917	
				67	1.19	836	
				50	0.65	685	
				32	0.37	606	
B-2	1.5	-	0.40	-	8.26	1864	50 mm
			0.45		15.44	2192	
			0.50		15.85	2136	
			0.55		15.06	2216	
			0.60		12.14	2101	
			0.65		11.98	2091	
			0.70		8.87	2192	
			0.75		7.96	2160	
			0.80		6.45	2064	
			0.85		4.93	2013	
B-3	1.5	-	0.40	50	5.52	1851	50 mm
			0.45		7.99	1744	
			0.50		13.67	1829	
			0.55		10.68	1747	
			0.60		6.32	1701	
			0.65		6.01	1627	
			0.70		6.65	1653	
			0.75		5.00	1635	
			0.80		4.39	1488	
			0.85		4.10	1635	

Table-1: Detail Proportion of Concrete Mixes and Properties of Lightweight Concrete

C: Cement Content; S: Sand Content; L: Lime Content; A: Aluminium, W: Water Content
All Content ratios are by weight
[a]kg/m^3
[b]MPa

Table-1: (Continued…)

Mix Design	S/C	C/L	W/C	C/A	Density[a]	Compressive Strength[b]	Mold Size
B-4	1.5	4.0	0.40	50	2.41	1659	50 mm
			0.45		6.21	1885	
			0.50		9.45	1939	
			0.55		8.51	1816	
			0.60		8.66	1840	
			0.65		6.50	1725	
			0.70		4.46	1605	
			0.75		3.49	1549	
			0.80		2.62	1363	
			0.85		2.07	1317	
B-5	1.5	4.0	0.60	100	4.95	1546	150 mm
			0.65		4.62	1574	
			0.70		3.91	1405	
			0.75		3.02	1383	
			0.80		3.38	1355	
			0.85		2.79	1263	
			0.90		2.23	1145	
			0.95		2.78	1215	
			1.00		2.32	1189	
			1.05		2.02	1084	
			1.10		1.32	1102	
			1.15		0.54	1093	
			1.20		0.34	1070	
B-6	1.5	4.0	0.75	50	0.99	1071	150 mm
			0.80		1.05	1010	
			0.85		0.97	1010	
			0.90		0.91	971	
			0.95		0.68	935	
			1.00		0.61	884	
			1.05		0.59	868	
			1.10		0.68	857	
			1.15		0.42	842	
			1.20		0.39	810	

C: Cement Content; S: Sand Content; L: Lime Content; A: Aluminium, W: Water Content
All Content ratios are by weight
[a]kg/m^3
[b]MPa

Significant change in density was observed when mold was changed from 50 mm to 150 mm. B-6 producing low density (<1000 kg/m^3) but low strength (<1 MPa) concrete. Absorption capacity and thermal conductivity (Lee's Method) of aircrete (<1000 kg/m^3) were determined and found within range of 20-25% and 0.2-0.5 W/m-k respectively.

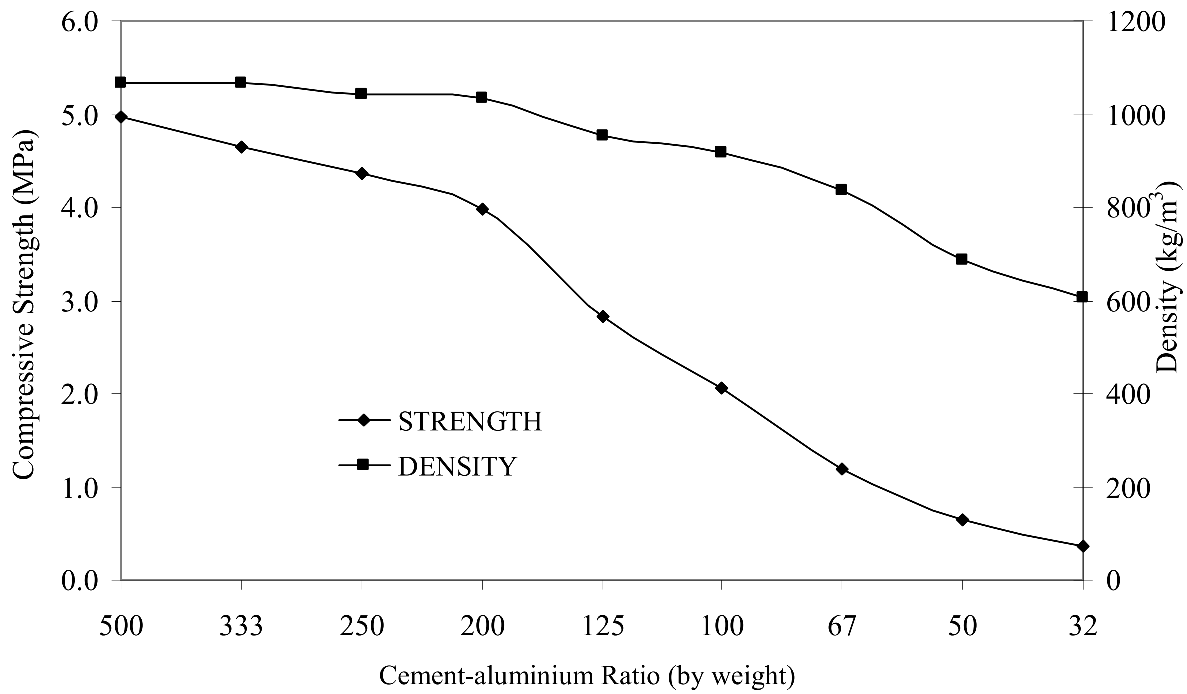

Figure 2: Effect of Aluminium content on density and compressive strength of hardened cement (1071 kg/m^3) with water (643 kg/m^3)

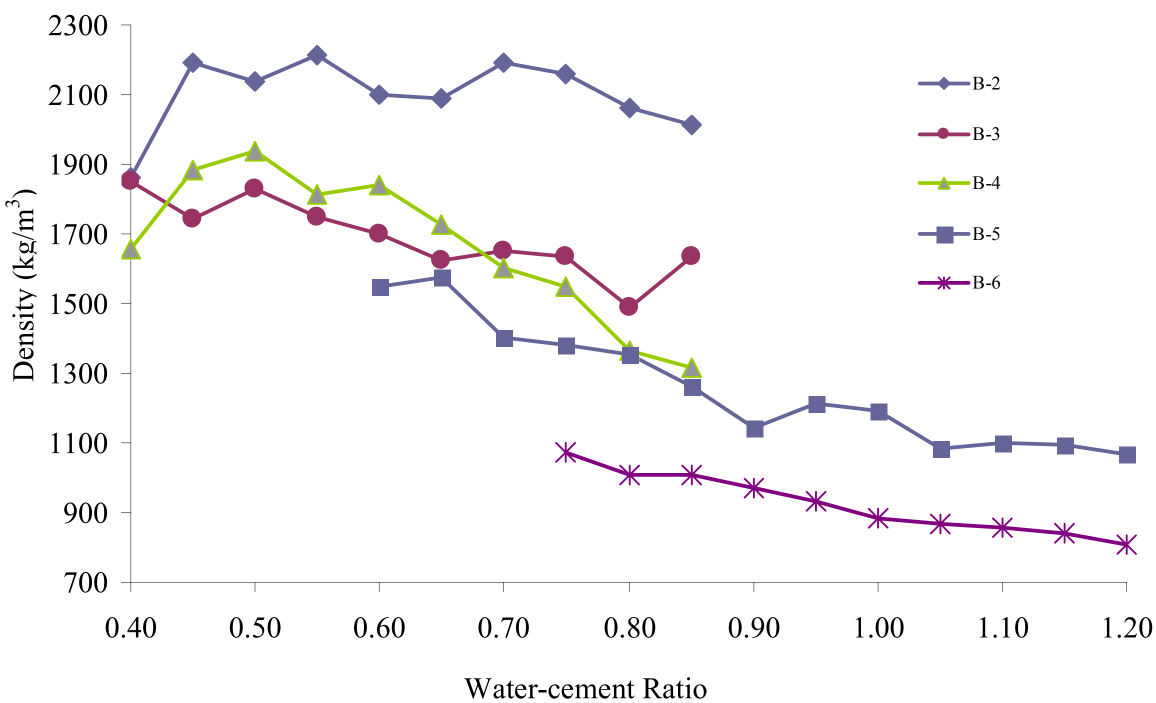

Figure 3: Relationship between density and water cement ratio

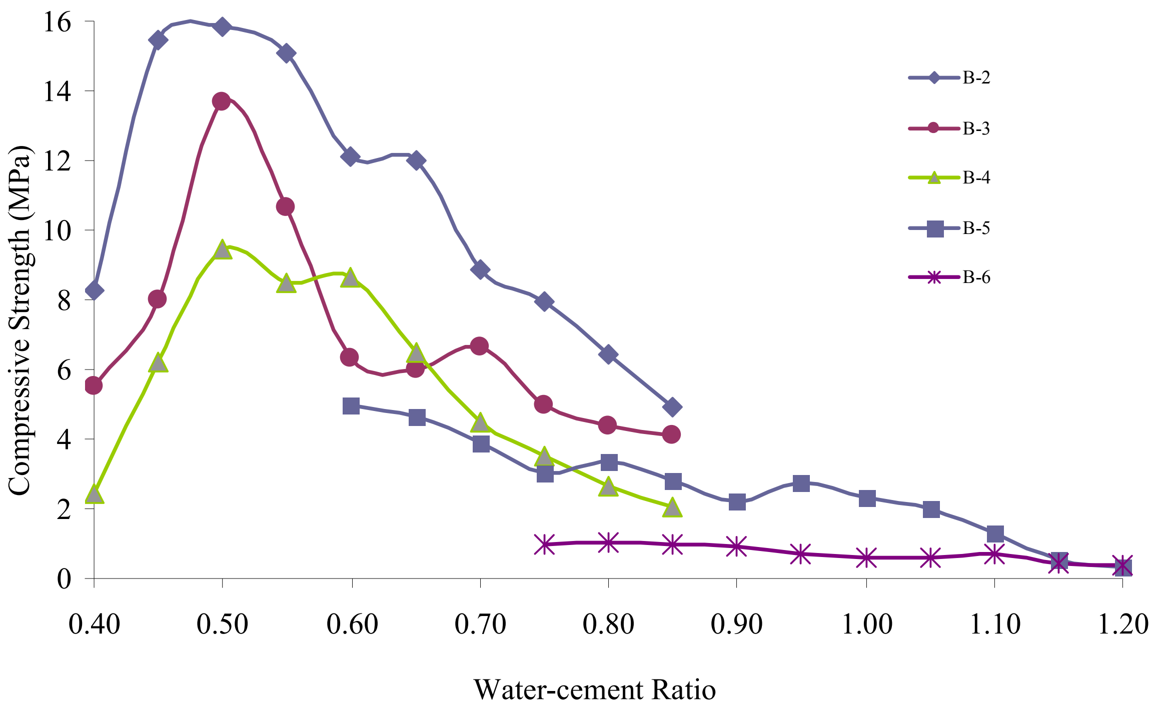

Figure 4: Relationship between compressive strength and water cement ratio

6.0 DISCUSSIONS

Aluminium powder was successfully able to introduce void in the mortar matrix as seen from Figure 2. With the progress of mix bands from B-2 to B-6, density can be reduced up to as low as 1000 to 700 kg/m^3 and subsequently strength reduced up to 2.0 to 0.40 MPa. Increased aluminium content would reduce the density but subsequently reduce the strength of hardened mortar. Mix proportion B-2 showed almost plateau density but sharply decreasing strength starting from water-cement ratio 0.50. No significant behavior could be characterized below water-cement ratio 0.50. This anomalous behavior may be due to zero compaction provided on the mixture thereby leaving large voids. However, water content played vital role in void stabilization in the matrix. Decreasing trend shown by mix proportions B-2, B-3 and B-4 suggested the water cement ratio to higher values up to 1.20. Moreover, density below 1000 kg/m^3 was found for water-cement ratio more than 0.90 in mix B-6. Neglecting anomalous fluctuation of density and compressive strength below water-cement ratio 0.50 of B-4, B-5 and B-6, exponential trend can be imposed on the relation as shown in Figure 5. Statistical comparison with extrapolation was done to idealize the relation between density, strength and water-cement ratio. Containing identical mix proportion, B-4 and B-6 are showing varied volumetric expansion due to increase in volume-surface ratio at a ratio 1:3. Increased cement-aluminium ratio; 100 to 50 led to increased volumetric expansion thereby reduced density as seen from the comparison of B-5 and B-6. However, density trend was more pronounced to characterize than that of strength. Section of cube samples suggested formation of voids 2 to 15 mm in size forming honeycomb structure.

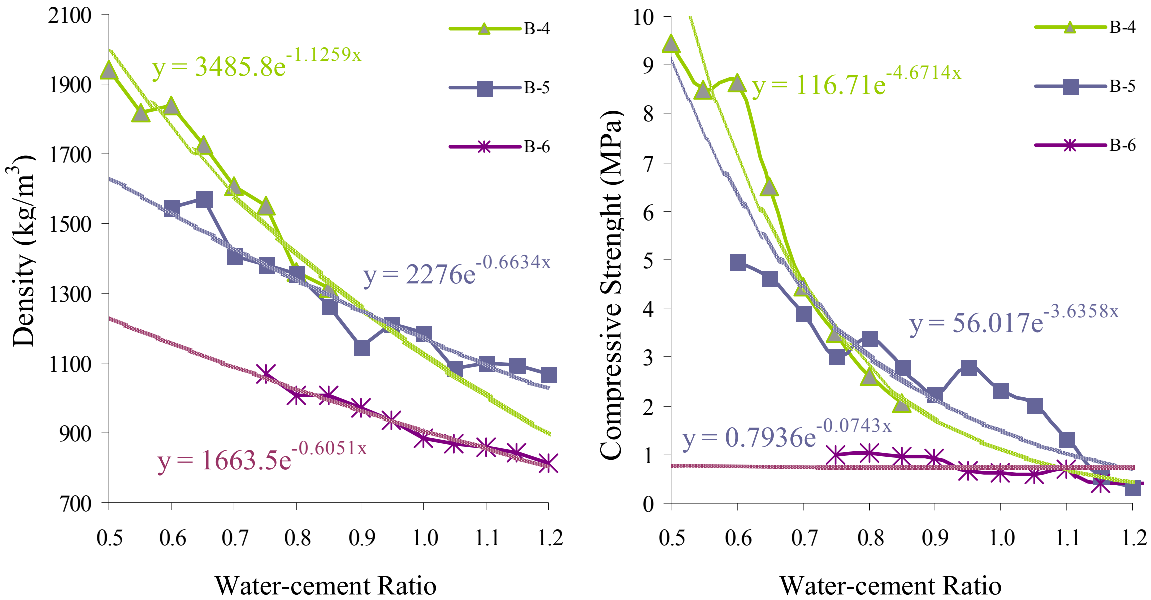

Figure 5: Comparison of Density and Compressive Strength due to increment of Volume-surface Ratio and Aluminium Content

7.0 FURTHER RESEARCH

Due to time and resource constrains, more detail study was not possible. Mix proportions with variable aggregate-cement ratio and cement-lime ratio should be applied to observe wide range of performance. Effort should be made to produce lightweight concrete using improved curing to achieve higher strength. Vapor curing at the initial stage of volumetric expansion may improve product quality. More material options (ordinary portland cement, plasticizer, viscous admixture) may be introduced to enhance performance.

8.0 CONCLUSIONS

The following conclusions can be drawn on the results of this investigation:

After a series of trials comprising indigenous options, density of concrete was able to be reduced within range of 700-1000 kg/m^3. However, strength was very low (0.5-2.0 MPa). Absorption capacity and thermal conductivity was within the range of 0.2-0.5 W/m-k.

As per RILEM classification, lightweight concrete produced in this research can be grouped under class-III and Insulating type lightweight concrete (RILEM 1978).

The reasons behind lower strength are high water-cement ratio, less cementation index and foamy honeycomb structure of hardened mortar.

Within the domain of water-cement ratio 0.50 to 1.20, density and compressive strength trend suggest 10 to 40% reduction in density and 50 to 90% reduction in strength due to increment of volume-surface ratio from 1:3 by introducing 150 mm cube in place of 50 mm cube whereas 20 to 25% density reduction and 0 to 80% strength reduction was observed by increasing cement-lime ratio from 100 to 50.

Finally, it can be concluded that lightweight concrete is feasible using indigenous materials and appropriate technology in Bangladesh.

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