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FIRED CERAMIC BRICKS FOR HOUSING CONSTRUCTION: COMPLIANCE TO COST RATIO (C-CR) ANALYSIS

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Abstract: This study involves compliance to cost ratio (C-CR) analysis of ceramic bricks for masonry work. Materials used in this study involves clay, wood saw dust (WSD) and waste glass (WG). Fired brick samples A, B, C, D, E, F, G and H contained 5% fixed amount of WSD and 0, 10, 15, 20, 25, 30, 35 and 40% WG respectively. The samples were examined for porosity, water absorption, saturation coefficient, linear shrinkage, initial suction rate, weight loss, bulk density, wear rate, thermal conductivity, compressive and flexural strength and efflorescence. The values of the properties of each sample were compared with values stipulated in various existing standards. Property evaluation index, Compliance Level and Compliance to Cost Ratio (C-CR) analysis were carried out. Compliance level of samples were 38, 46, 77, 92, 85, 92, 85, 100%, indicating that as WG additive increased in the samples, level of compliance of samples with existing standard adopted in this study, increased. Brick sample D (20% WG and 5% WSD), with compliance level of 92% had the highest Compliance to Cost Ratio value of 7.6475, hence selected as optimum sample for masonry bricks.
Keywords: properties evaluation, housing, brick samples, fired clay bricks, Compliance to Cost Ratio (C-CR)

1. INTRODUCTION

Housing and shelter remains a very important need of man. As population continues to rise all over the world, housing deficit is on the rise which requires attention in tackling. Despite government interventions in providing houses, yearly demand is still on the rise. Migration from rural areas to cities has led to population explosion in the cities, leading to rise in the demand for few houses available. Since demand for houses is more than the available houses, house rent continues to rise. Provision of social amenities such as housing in rural areas can help reduce migration from rural areas to cities.

This high housing deficit is as a result of some factors one of which is high cost of building materials like ordinary Portland cement OPC, commonly used in making concrete bricks in modern day masonry. Work has been carried out in using clay bricks as alternative building bricks since clay has good workability, its relatively cheap, and it availability in our immediate environment [15, 17]. The use of this clay is cost effective and energy saving [29]. Many researchers have utilized environmental wastes in production of bricks by adding these wastes to clay. Theses wastes include wood saw dust, bamboo ashes, rise husk, charcoal and other wastes while others are industrial wastes and by products like industrial sludge, waste glass, fly ash, coal mining and petroleum refining waste and others [9, 11, 12, 16, 18, 22, 24, 26, 25]. These wastes were added to improve properties of fired bricks for various applications ranging from masonry to refractory.

Various studies accounted for the properties and influence of the waste addition on the properties of such bricks. However, there is no account for compliance of such bricks with existing standards. There was no evaluation of the compliance level of the bricks samples with respect to the experimental cost incurred in producing the samples. C-CR analyses the influence of the properties with respect to the cost incurred, and provide a way of selecting optimum sample for a given application putting into consideration level of compliance with existing standards.

Hence, this research work involved selection of "optimum" sample fired ceramic bricks containing waste glass and wood saw dust additives using Compliance to Cost Ratio (C-CR) analysis

Table 1. Mix proportion of samples produced.

Samples	Waste glass (%)	Saw dust (%)	Clay (%)
A	0	0	100
B	10	5	85
C	15	5	80
D	20	5	75
E	25	5	70
F	30	5	65
G	35	5	60
H	40	5	55

2. MATERIALS AND EXPERIMENTAL PROCEDURE

The materials used are clay, waste glass (WG) and wood saw dust (WSD). 600Kg of clay was bought at N 6.77/kg, while 90Kg of WSD was bought as N 1.87/Kg. Glass bottles regarded as waste were bought at N 15.14/Kg, after washing, grinding and sieving the cost was N 23.78/Kg. Clay was sundried for 3 days, broken into lumps, milled and sieved to -150 µm, while the WSD was dried and sieved to -850 µm. The samples were prepared by the mixing of WG, WSD, and Clay at varied proportions, with water addition. Control sample A was prepared by adding water to clay and the slurry extruded into a rectangular mould 190 x 90 x 90 mm and compressed at 10MPa. Sample B to H were prepared using the same procedure with 5% fixed amount of waste dust and varied proportion of WG content, as shown in table 1. The green bricks were left in the open atmosphere for 12 hours to allow stability before been weighed and dried in an oven at 5 ºC/min until 800 ºC was attained. The brick samples were soaked for 2 hours and then allowed to cool in the furnace before been tested for apparent porosity, water absorption, weight loss, saturation coefficient, initial suction rate, linear shrinkage, bulk density, compressive strength, wear rate, thermal conductivity and efflorescence.

Table 2. Test methods and standard procedures followed

Test for	Standard Procedure
Porosity	ASTM C373-14a (2014) [5]
Water Absorption (24hrs immersion)	ASTM C373-88 (2006) [6], IS 3495 (1992) [20]
Water absorption (5hrs boiling)	ASTM C373-88 (2006) [6]
Saturation Coefficient	ASTM C67/C67M-19 (2019) [8]
Initial Suction Rate	ASTM C67/C67M (2019) [8]
Linear Shrinkage	ASTM C326-09 (2018) [4]
Bulk Density	ASTM C373-88 (2006) [6]
Compressive Strength	ASTM C1314-18 (2018) [1]
Flexural Strength	ASTM 293/C293M (2016) [3]
Wear rate	IS 13801 (1993) [19]
Thermal Conductivity	ASTM C177-19 (2019) [2]
Efflorescence	IS 3495 (1992) [20]
Weight loss	ASTM C67/C67M-19 (2019) [8]

3. RESULTS AND DISCUSSION

Table 3, shows the values for the properties of each sample. From the result, the additives have a reducing effect on apparent porosity, water absorption, initial suction rate, linear shrinkage, weight loss and wear depth while there was an increasing effect on bulk density, compressive strength, flexural strength, and thermal conductivity. In the case of efflorescence, the samples tested fell between slight and moderate which still met requirement for bricks as per [20].

In carrying out C-CR analysis, the following steps were taken:

» Recording the value of properties obtained during tests.
» Obtaining the standard values for properties of masonry brick.
» Obtaining property evaluation index and total value under each sample
» Evaluating the compliance index for each sample
» Accounting for the mass of each composition in each sample and evaluating experimental cost of each sample
» Obtaining the Cost Ratio CR for each composition and Total Cost Ratio (TCR) of each sample

— **Recording the value of properties obtained during tests**

The values of properties obtained during test are represented in table 3.

Table 3: Table of values of properties

Samples (with 5% fixed amount of saw dust and varied proportion of waste glass)								
Properties	A (0%WG)	B (10%WG)	C (15%WG)	D (20%WG)	E (25%WG)	F (30%WG)	G (35%WG)	H (40%WG)
Apparent Porosity (%)	36.6	36.9	33.3	29.4	26.3	22.9	19.2	15.6
Water Absorption (24hrs immersion) (%)	25.2	25.3	23.1	20.7	18.4	15.8	14.4	13.6
Water Absorption (5Hrs boiling) (%)	26.0	27.8	26.0	23.8	19.8	16.0	14.5	15.6
Saturation Coefficient	0.97	0.91	0.89	0.87	0.93	0.99	0.99	0.87
Initial suction rate Kg/m^2.min	2.44	1.87	1.66	0.85	0.21	0.37	0.20	0.26
Linear shrinkage (%)	8.10	6.39	5.82	6.11	4.21	4.83	4.11	3.97
Bulk Density (g/cm^3)	1.48	1.53	1.64	1.73	1.86	1.92	1.98	2.02
Compressive Strength (MPa)	11.8	12.1	13.5	15.4	17.5	19.7	21.3	22.5
Flexural strength (MPa)	1.84	1.95	2.22	2.64	3.30	4.32	3.72	3.35
Wear Depth (mm)	3.51	3.22	2.70	2.23	1.72	1.51	1.36	1.25
Thermal conductivity (W/mK)	0.21	0.21	0.24	0.27	0.32	0.39	0.43	0.46
Weight loss (%)	8.33	6.54	5.71	6.11	4.43	5.81	3.33	3.21
Efflorescence	37% Moderate	18% Moderate	24% Moderate	15% Moderate	24% Moderate	16% Moderate	8% Slight	9% Slight

— **Obtaining the standard values for properties of masonry brick**

Table 4 shows standard values for properties of masonry bricks adopted in this study

Table 4: Property Evaluation for Each Sample

Properties	Standard Value	Source	QS(Samples that met standard)
Linear Shrinkage	Less than 8%	CNS 1127 [14]	A,B, C, D, E, F, G, H
Bulk density	1.6 g/cm^3	TCVN 1451:1998 [23]	B, C, D, E, F, G, H
Apparent Porosity	Less than 30%	BS 3921 (1985)	E, F, G, H
Water absorption (24hrs immersion)	Less than 20%	ASTM C62 -04 (2004) [7] & SNI 15-2094 (2000) [21]	E, F, G, H
Water absorption (5hrs boiling)	Less than 25%	ASTM C67/67M-19 (2019) [8]	B,C, D, E, F, G, H
Saturation Coefficient	Less than 0.9 for normal weather	ASTM 67/67M-19 (2019) [8]	C, D, H
Weight loss	Less than 15%	TS 704 [28]	A, B,C, D, E, F, G, H
Efflorescence	0-50%	IS 3495 (1992) [20]	A, B, C, D, E, F, G, H
Initial Suction Rate	Between 0.25 to 1.5 Kg/m^2. min	BS 3921:1985 (1985) [13]	A, B, C, D,
Compressive Strength	Greater than 5MPa (low rise building)	BS 3921 (1985) [13]	A, B, C, D, E, F, G, H
Thermal conductivity	Not greater than 0.6 W/mK	ASTM C-177, (2019) [2]	A, B, C, D, E, F, G, H
Flexural Strength	2MPa	AS 3700, (2001) [10]	C, D, E, F, G, H
Wear rate	3mm	TS 2824-1338 [27]	C, D, E, F, G H

QS Qualified Sample

— Property Evaluation of Samples

After obtaining the values of properties for each sample, these values were compared with standard values adopted for this study and as stated in table 4. The value for each sample in table 3 was compared with the standard value for each property in table 4. Where the property value in table 3 met the standard value in table 4, 1 was recorded for such property under each sample in table 5. Where the value failed to meet standard value, 0 was recorded in table 5. For instance, comparing the apparent porosity value for sample A to H in table 3 with the standard value of <30% in table 4, sample D, E, F, G and H had below BS 3921 [13] value of 30%. Thus in table 5, 1 was used for porosity under sample D, E, F, G and H while in the case of other samples which failed to meet the standard value (i.e. have above 30%), 0 was recorded in table 5 under samples A, B, and C. Similarly, in the case of bulk density, samples C, D, E, F, G and H had their values above 1.6 g/cm^3 as per [23]; hence in table 5, 1 was recorded under each sample while 0 was recorded under samples A and B. This procedure was followed until table 5 was complete. At the end, the numbers were added and total value of index was obtained.

Table 5: Property evaluation Index for each Sample

	Samples (with 5% fixed amount of saw dust and varied proportion of waste glass)							
Properties	A (0 WG)	B (10%WG)	C (15%WG)	D (20%WG)	E (25%WG)	F (30%WG)	G (35%WG)	H (40%WG)
Apparent Porosity	0	0	0	1	1	1	1	1
Water Absorption (24hrs immersion)	0	0	0	0	1	1	1	1
Water Absorption (5Hrs boiling)	0	0	0	1	1	1	1	1
Saturation Coefficient	0	0	1	1	0	0	0	1
Initial suction rate	1	1	1	1	0	1	0	1
Linear shrinkage	0	1	1	1	1	1	1	1
Bulk Density	0	0	1	1	1	1	1	1
Compressive Strength	1	1	1	1	1	1	1	1
Flexural strength	0	0	1	1	1	1	1	1
Wear rate	0	0	1	1	1	1	1	1
Thermal conductivity	1	1	1	1	1	1	1	1
Weight loss	1	1	1	1	1	1	1	1
Efflorescence	1	1	1	1	1	1	1	1
Total value	5	6	10	12	11	12	11	13

— Compliance Index

Compliance Index for each sample was evaluated using equation 1

$$\text{Compliance Index} = \frac{\text{Total Value for each sample}}{\text{Total expected Value}} \times 100 \quad (1)$$

Total expected value refers to total number of standards adopted in this study, which is 13. Table 6 shows increase in compliance level from sample A and B with compliance of 38% and 46% respectively, to 100% in sample H. As the additives continued to rise, properties were improved leading to higher level of compliance.

Table 6: Compliance Level for each sample

Samples	A	B	C	D	E	F	G	H
Compliance Level (%)	38	46	77	92	85	92	85	100

— Weight and Cost Analysis

Going by percentage weight composition as stated in table 1, the mass and cost were analyzed in table 7 and 8.

The cost of each sample was evaluated for clay as N 6.77/Kg, for WSD as N 1.87/kg and WG as N 23.78/kg. Labour cost of crushing, milling and sieving was evaluated as N10,000 for the 412 bricks produced, while N 12,000 was evaluated for cost of firing which were fixed cost. Fixed cost amounts to N 53.40/sample

Table 7: Mass and cost of composition in each sample

Samples	A	B	C	D	E	F	G	H	Total (g)
Clay	1500	1275	1200	1125	1050	975	900	825	8850
WSD	0	75	75	75	75	75	75	75	525
WG	0	150	225	300	375	450	525	600	2625
Cost of composition in each sample (N)									
Samples	A	B	C	D	E	F	G	H	Total (N)
Clay	10.16	8.63	8.00	7.50	7.00	6.50	6.00	5.50	59.29
WSD	0	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.98
WG	0	3.57	5.35	7.13	8.92	10.70	12.45	14.27	62.39
Cost of compositions	10.16	12.34	13.49	14.77	16.06	17.34	18.59	19.91	122.66

Table 8: Summary of Cost

Samples	A	B	C	D	E	F	G	H
Cost of Composition (N)	10.16	12.34	13.49	14.77	16.06	17.34	18.59	19.91
Fixed Cost (N)	53.40	53.40	53.40	53.40	53.40	53.40	53.40	53.40
Experimental Cost of each sample (N)	63.56	65.74	66.89	68.17	69.46	70.74	71.99	73.31

— Cost Ratio and Compliance to Cost ratio

≡ Cost Ratio (CR)

Cost ratio is the ratio of cost on each component in each sample to the cost expended on the materials.

$$\text{Cost Ratio} = \frac{\text{Cost on each component in each sample}}{\text{cost expended on all components in each sample}} \quad (2)$$

Table 9: Cost Ratio analysis

	Cost Ratio of each component in each sample							
	A	B	C	D	E	F	G	H
Clay	0.0828	0.0704	0.0652	0.0611	0.0571	0.0530	0.0489	0.0448
WSD	0	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
WG	0	0.0291	0.0435	0.0581	0.0727	0.0872	0.1015	0.1163
Total CR	0.0828	0.1006	0.1098	0.1203	0.1309	0.1413	0.1515	0.1622

≡ Compliance to Cost Ratio (C-CR)

$$\text{C-CR for each sample} = \frac{\text{Compliance}}{\text{Total Cost Ratio}} \quad (3)$$

Table 10: Compliance to Cost Ratio (C-CR)

Samples	A	B	C	D	E	F	G	H
Compliance (%)	38	46	77	92	85	92	85	100
Cost of composition in each sample	10.16	12.34	13.49	14.77	16.06	17.34	18.59	19.91
Total Cost Ratio	0.0828	0.1006	0.1098	0.1203	0.1309	0.1413	0.1515	0.1622
C-CR	4.5894	4.5726	7.0128	7.6475	6.4935	6.5110	5.6106	6.1652

— Cost Ratio and Compliance to Cost Ratio curves

From figure 1, it can be observed that cost ratio continues to rise from sample A with no additives to sample H (40% WG and 5% WSD). This implies that as additives increases in the sample, cost of production continued to rise.

From figure 2, sample H which had 100% compliance has a lower C-CR compared to sample D (20% WG and 5% WSD) which has highest C-CR of 7.6475 despite its lower compliance level of 92% when compared to sample H. It's more economical to employ sample D in construction than sample H. Sample D has the highest C-CR of all the samples analysed in this study, indicating that it will be the most cost effective sample with maximum impact in service. Therefore sample with 20% WG and 5% WSD is the selected sample.

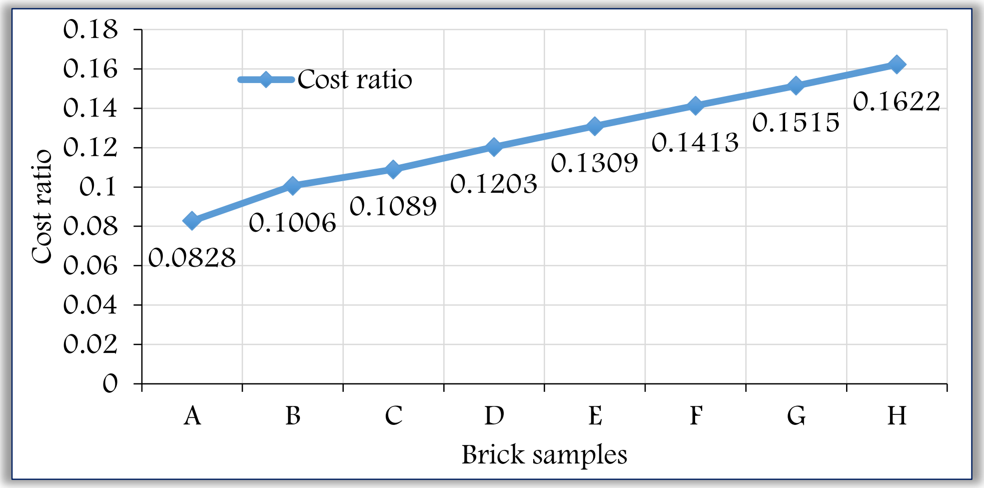

Figure 1: Variation in Cost Ratio of samples

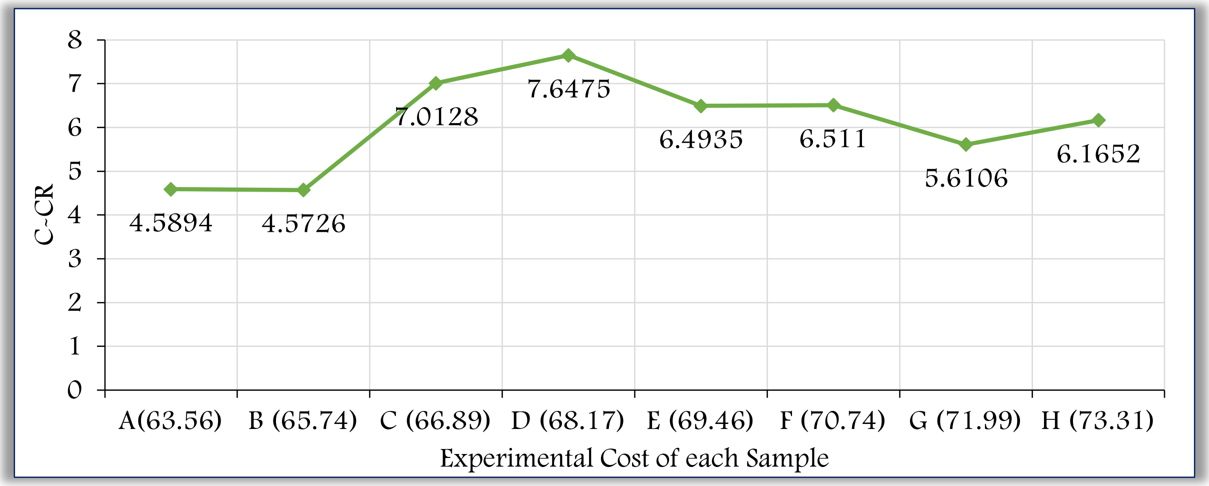

Figure 2: C-CR curve

4. CONCLUSION

This study compared the property values of fired ceramic bricks containing WSD and WG at varied proportion with standard value, after which property evaluation and compliance level was evaluated. Further analysis involves the Compliance to Cost ratio from which maximum value of 7.6475 was obtained for sample D (20% WG and 5% WSD). Therefore, 20% waste glass and 5% wood saw dust addition to clay produced bricks will be durable for construction of houses. Further study may involve C-CR analysis of fired bricks containing 3% WSD with 0 to 40% WG content.

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