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Load–Bearing Capacity of Concrete Hollow Blocks Containing Rice Husks

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Abstract

This research measures the feasibility of Rice Husks (RH) as additves in cement–aggregate mixture of a load–bearing Concrete Hollow Block (CHB). Results show that 4% of Pulverized Rice Husks (PRH) mixed with cement, and aggregates at 1:3 mix ratio, plus water, gives a compressive strength of 10.72 MPa (1,555 psi) and 11.39 MPa (1,652 psi) at age 14 and 28 days, respectively, of a load–bearing CHB in conformity with the ACI, British, and Philippine National Standards.

Concrete Hollow Blocks (CHB) containing PRH result to a higher compressive strength compared to CHB's containing Unpulverized Rice Husks (URH); 1% and 2.6% by weight URH mixed with 1:3 ratio of cement and aggregates, give 8.64 MPa (1,254 psi) and 7.30 MPa (1,059 psi), respectively, at age 28 days. A mix ratio of 1:5 at 1% URH gives 7.05 MPa (1,023 psi).

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Introduction

In recent years, there has been an increased awareness made by the Department of Environment and Natural Resources (DENR) on illegal quarry along rivers, streams and seashores. Aggregates are now limited making CHB expensive. Agro–waste products such as bagasse, reeds and straw, banana stalks and leaves, and rice husks in particular, can be used as alternative materials for masonry construction. Rice Husks can be added to sand in casting load–bearing CHB's. Rice husks as wastes are not essentially connected with building or masonry construction; however, with special processing and treatment, or in conjunction with other materials, they can economically be a replacement to, or used to improve the quality of, conventional building materials. Other recycled materials are those from demolished buildings, which continue to serve as building materials in numerous ways; and from industries and households however, they cannot be used as additives to CHB's.

With the aid of technology, indigenous materials such as Rice Husks can be studied scientifically and evaluated with the end view of utilizing these materials in construction. The increasing demand of building materials plus their limited availability and skyrocketing cost motivated some researchers to look for alternative housing components which are locally available, cheaper than conventional materials and of satisfactory quality. Some studies focus on the utilization of agricultural waste materials that result in the development of particle boards, cement–bonded boards and hollow blocks.

With the current interests to find for alternative construction materials, this research intends to study the suitability of rice husks and aggregates as additive to load-bearing CHB's for masonry construction.

Objectives of the Study

This study is conducted with the following objectives:

1. to reveal if rice husks, when mixed with Portland cement and sand, can reach the required compressive strength of a load-bearing concrete hollow block;
2. to determine the amount of rice husks and sand aggregates needed to produce load-bearing CHB's;

3. to evaluate the effect of different levels of rice husks and sand aggregates to the compressive strength of load-bearing CHB's and
4. to examine if Pulverized Rice Husks (PRH) will have greater compressive strength than Unpulverized Rice Husks (URH).

Review of Related Literature

Concrete block is another term for hollow load–bearing concrete masonry unit. It is typically made from a low slump concrete mix. Manufacturing methods vary from hand–made procedure in small production scales to fully mechanized procedure in industrialized plants with large production capacity. These units are generally used for reinforced, fully grouted bearing walls and shear walls, but can also be used in cavity walls, confined masonry and non–structural masonry (Yamin & Garcia, 1994).

Indigenous building materials have two inherent advantages over other materials – low cost and domestic availability. Developing countries, which are particularly humid, continue to rely on indigenous materials. These countries support the growth of plants and forests and a variety of materials such as grasses, bamboo, timber and allied materials for home–building purposes (Moavenzadeh, 1990).

Design of a sustainable agricultural, household, industrial and other waste–recycling scheme depends not only on the technical aspects, but also on public health, environment, socio–economic and cultural considerations. Although waste recycling has been practiced successfully in both developed and developing countries, a large number of people still lack an understanding of the benefits to be gained from these waste–recycling schemes (Chongrak, 1996).

The technology in CHB's was developed in the Philippines some years ago as a substitute/alternative to the traditionally commercial sand–cement mortar hollow block, the price of which continues to rise due to the growing scarcity of sand and the increase in transportation cost resulting from the oil crisis. The principal components of this type of hollow block are soil (reddish hill soil), rice husks and Portland cement. The average compressive strength of six tests with 1:2:3 ratio (cement, soil, and RH) was 1,367 kPa or 198.2 psi after 14 days based on the gross area of the block. (Philippines' Forest Products Research and Development Institute – FPRDI).

Lightweight aggregates are classified as those minerals, natural rock materials, rock-like products, and by-products of manufacturing processes used as bulk fillers in concrete building blocks. Most lightweight aggregates and aggregate materials are bulky and low in unit value. Usually, they cannot be transported to great distances in their final form, yet still remain competitive with alternative building materials (Moavenzadeh, 1990).

Rice husks can be used as additives in the fabrication of CHB's containing soil and cement; or as the principal aggregates in the production of lightweight bricks and hollow or solid building blocks for construction of non-structural frameworks. Rice husks have low conductivity (K value) and, thus, are very good insulating materials for use in house construction, farm structures, cold storage plants, etc. It can be fire-resistant after being soaked in a solution of boric acid and borax (Lauricio, 1987).

The compressive strength of Type I Class A load-bearing Concrete Hollow Blocks is 6.86 MPa (1,000 psi) for an average of 3 tests (PNS 16:1984). UBC and ASTM standards provide the minimum compressive strength requirement of 1,000 psi for an average of 3 tests based on the net area of the concrete hollow block.

Methodology

1. Actual Samples Used in the Experiment

Rice husks are taken from Maranding, Lanao del Norte. These are divided into two parts: one part is pulverized and the other part is unpulverized. The sand aggregates are acquired from quarries of Iligan City. The mixing water is taken from MSU–IIT waterlines. Type–I Portland cement is used (PNS 07:1983) for all mixes.

2. Pertinent ASTM Standards Used

a. ASTM C 140–91
b. ASTM C 29
c. ASTM C 128
d. ASTM C 90–90

3. Method of Pulverizing the Rice Husks

A volume of rice husks is passed in the funnel-shaped container connected to the Hammer milling machine. The machine has a screen at the bottom part where the milled Rice Husks are sieved.

4. **Data Sampling**

Cement and sand are proportioned at 1:3, 1:5 and 1:7, respectively, by weight. Each batch mix produces 6 specimens of 1%, 2.6% and 4% URH by weight of aggregates. A total of 54 specimens are produced out of this mix. Another 54 specimens using the mix ratios as stated above are prepared; however for these specimens, PRH are added with the same percentages as stated above.

5. **Concrete Hollow Block Dimensioning**

A #2 size designation (390 mm x 150 mm x 190 mm) for concrete hollow blocks size is acquired (PNS 16:1984).

6. **Sieve Analysis for Sand Aggregates**

Maximum size of aggregates used in this study is ?". Of the total aggregates used, eighty percent pass through #4 sieve and twenty percent is the aggregates retained.

7. **Mixing and Casting**

Rice Husks are mixed with cement and aggregates using a shovel. Eighty percent of the total amount of water is added during the initial mixing process, and the remaining twenty percent in the final mixing process. The mix is then placed in the mould at one-thirds of its volume and tamped. This process is repeated for the second and final third resulting into a mound. Final leveling off is done by tamping steel plate on the mound. The mould is removed slowly in a secured area away from direct sunlight.

8. **Curing**

Curing is applied to CHB samples. These samples are positioned in the curing tank and sprinkled with water allowing them to be wet for 72 hours. Water curing after casting is required to prevent the water needed for the hydration of the cement from evaporating.

9. **Compression Test**

Two of 1"–thick wooden planks are used as capping of the ready–to–test CHB. Apply the load up to one half of the expected maximum load at any convenient rate, after which adjust the controls of the machine such that load is applied at a uniform rate and that failure occurs in not less than one nor more than two minutes. The formula is as shown below:

$$f = \frac{\text{Maximum Load Applied}}{\text{Net Area of CHB}} = \frac{N}{mm^2} = MPa$$

Net Area = $(0.39)(0.15) - 3\delta(0.05)^2$ = $0.03494\ m^2$

Note: The Net Area was computed from the actual size of mould used.

10. **Research Design**

Two separate Three Factor Fixed–Effect Model experimental design was used in order to scrutinize the implication of each factor and the interactions among them. The three factors considered are the following: Factor A – the cement-aggregate mix ratio, Factor B – the amount of rice husks in percent, and Factor C – the type of rice husks.

11. **Statistical Analysis of Data**

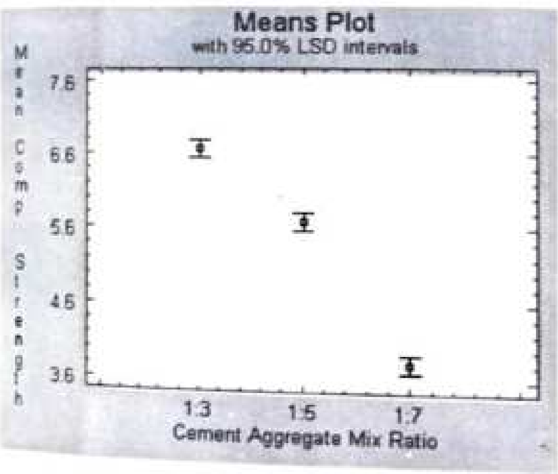
The Analysis of Variance (ANOVA) was accomplished using the Statlets.exe software downloaded free from the internet. The level of significance for the Three–Factor Fixed Effect Model is at 5%. The Analysis of Variance (ANOVA) table is shown in Table 1. Statistical equations are shown in Appendix A.

Table 1. ANOVA Table for the Three – Factor Fixed Effect Model

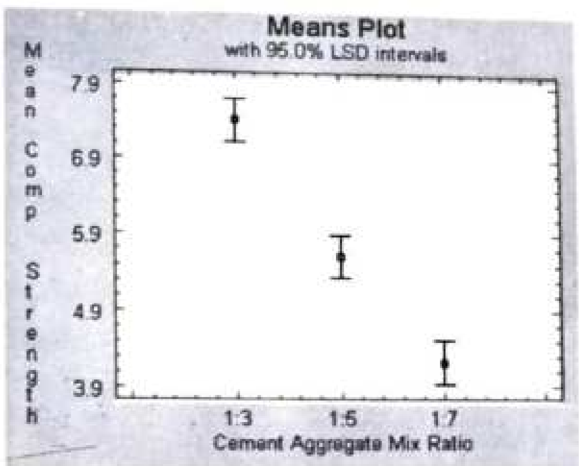
Source of Variance	Sum of Square	Degrees of Freedom	Mean Square	Fo
A	SS_A	$a-1$	MS_A	MS_A / MS_E
B	SS_B	$b-1$	MS_B	MS_B / MS_E
C	SS_C	$c-1$	MS_C	MS_C / MS_E
AB	SS_{AB}	$(a-1)(b-1)$	MS_{AB}	MS_{AB} / MS_E
AC	SS_{AC}	$(a-1)(c-1)$	MS_{AC}	MS_{AC} / MS_E
BC	SS_{BC}	$(b-1)(c-1)$	MS_{BC}	MS_{BC} / MS_E
ABC	SS_{ABC}	$(a-1)(b-1)(c-1)$	MS_{ABC}	MS_{ABC} / MS_E
ERROR	SS_E	Abs (n – 1)	MS_E	
TOTAL	SS_T	Abcn – 1		

Results and Discussions

1. Mean Compressive Strength vs. Cement–Aggregate Mix Ratio



(a) Means Plot at Age 14 days

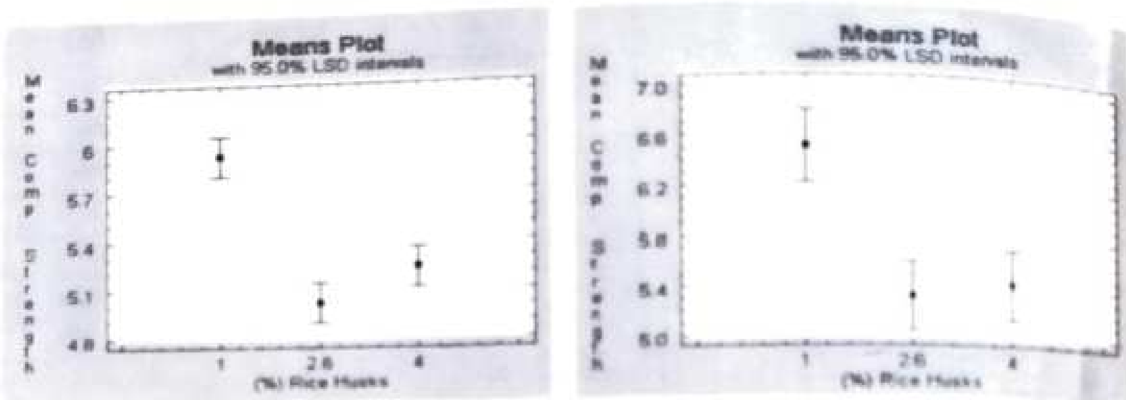


(b) Means Plot at Age 28 days

Figure 1. *Mean Compressive Strength vs. Cement – Aggregate Mix Ratio.*

The variation of cement–aggregate mix ratio greatly affects the compressive strength of Concrete Hollow Blocks (CHB's) as shown in Figure 1. The compressive strength of CHB's is inversely proportional to cement–aggregate mix ratio. Likewise, for the same mix ratio, the compressive strength is higher at age 28 days than at age 14 days.

2. Mean Compressive Strength vs. Amount of Rice Husks

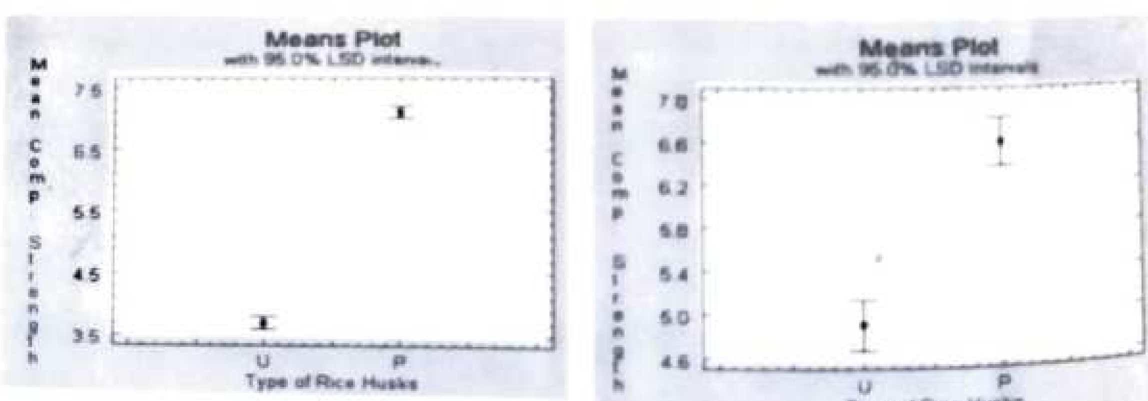


(a) Means Plot at Age 14 days **(b)** Means Plot at Age 28 days

Figure 2. Mean Compressive Strength vs. (%) Rice Husks

Figure 2 shows that the mean compressive strength of CHB's containing Rice Husks at 1% by weight gives higher value compared to CHB's with RH at 2.6% and 4%, respectively. But the compressive strength of CHB's at 2.6% RH is less than those with 4% RH. There is a corresponding increase in compressive strength from age 14 days to 28 days.

3. Mean Compressive Strength vs. Type of Rice Husks

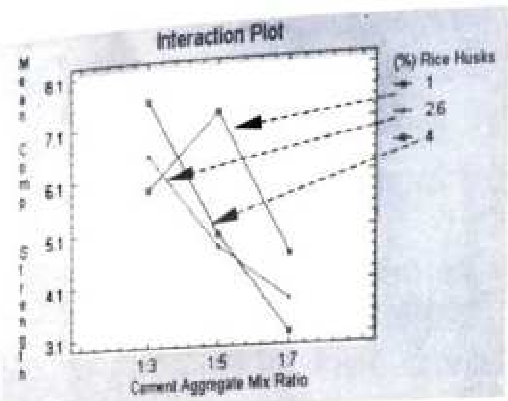


(a) Means Plot at Age 14 days **(b)** Means Plot at Age 28 days

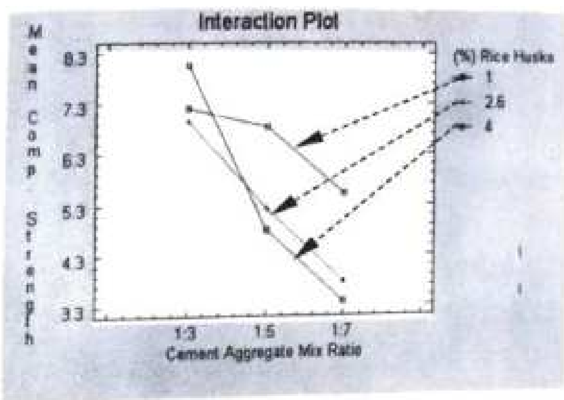
Figure 3. *Mean Compressive Strength vs. Type of Rice Husks*

The means plot shown in Figure 3 implies that CHB's containing Pulverized Rice Husks (PRH) have greater compressive strength than those containing URH. The mean compressive strength of CHB's with PRH at age 28 days is less than that at age 14 days, while the observation made at age 14 days for compressive strength of CHB's with URH increased at age 28 days.

4. Interaction Plots of Factors A, B and C



(a) Interaction Plot at Age 14 days

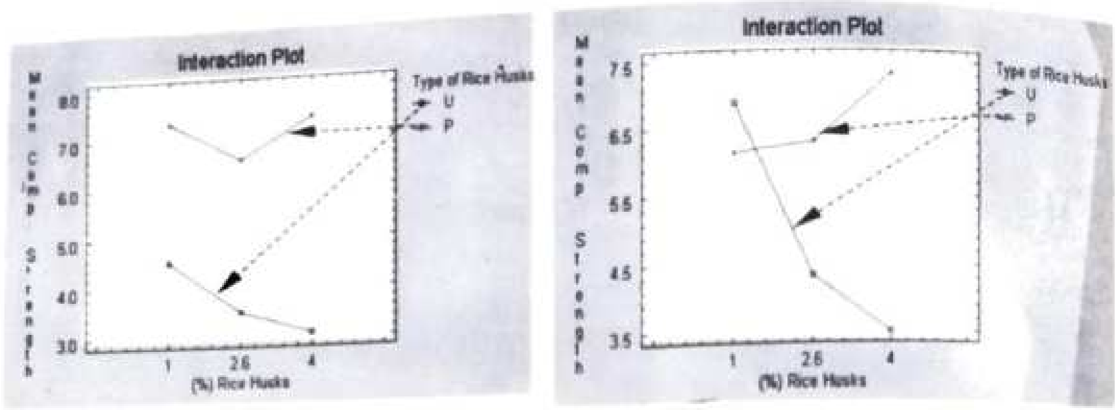


(b) Interaction Plot at Age 28 days

Figure 4. *Mean Compressive Strength vs. Interaction of Factors A & B*

This plot in Figure 4 shows a significant interaction between cement–aggregate mix ratio and amount of RH. This is signified by the non–parallelism of the lines. The compressive strength of CHB's at 1:7 mix ratio is less than those at 1:3 and 1:5 mix ratios, respectively, as shown in Figure 4(a). In Figure 4(b), CHB's with 1:3 mix ratio bears the highest compressive strength among those with the other mix ratios. CHB's containing 4% RH at 1:3 mix ratio give the highest compressive strength at ages 14 and 28 days.

5. Interaction Plots of Factors B and C

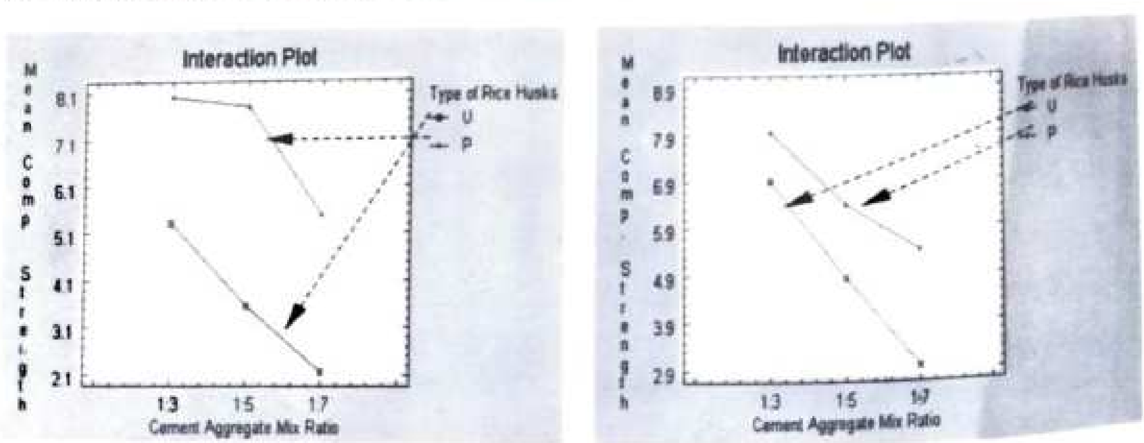


(a) Interaction Plot at Age 14 days **(b)** Interaction Plot at Age 28 days

Figure 5. *Mean Compressive Strength vs. Interaction of Factors B & C*

Figure 5(a) shows almost no difference between the mean compressive strength and the interaction of Factors B and C from 1% to 2.6%, but differs from 2.6% to 4%. Figure 5b shows that Concrete Hollow Blocks (CHB's) containing PRH has an increase in compressive strength with an increase in the amount of PRH. However, compressive strength of CHB's containing URH decreases with an increase in the amount of URH.

6. Interaction Plots of Factors A and C

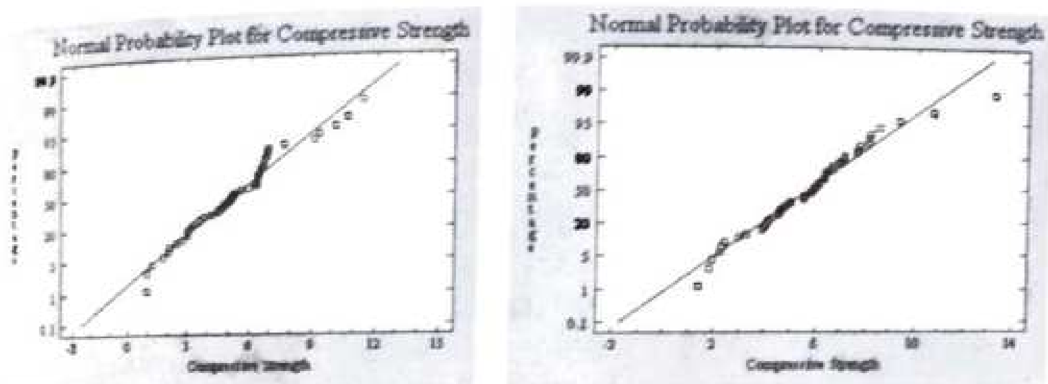


(a) Interaction Plot at Age 14 days **(b)** Interaction Plot at Age 28 days

Figure 6. *Mean Compressive Strength vs. Interaction of Factors A & C*

Figure 6 gives the significant difference in compressive strength CHB's containing URH and PRH. CHB's containing PRH provide greater compressive strength than those containing URH. The interaction also characterizes a decrease in compressive strength with respect to Factor A from mix ratios of 1:3, 1:5, to 1:7 for both observations at age 14 and 28 days, respectively.

7. Residual Probability Plot



(a) Normal Probability Plot at Age 14 days

(b) Normal Probability Plot at Age 28 days

***Figure** 7. Residual Probability Plot*

In Figures 7(a) and 7(b), the points are lying very close to a straight line. This condition implies that the distribution is very normal. However, there are two points in Figure 7(b) that are far from the group and cannot be judged as a basis of the problem. This may be due to human factors such as inaccuracies and approximations made during the experiment

Conclusions

The result of this study drew the following conclusions:

1. Rice Husks, when mixed with Portland cement and sand, can achieve the 1,000 psi required compressive strength of a load-bearing concrete hollow block as stipulated in ACI, British, and Philippine National Stan-

dards.

2. CHB's containing PRH has greater compressive strengths than those containing URH.
3. Different levels of rice husks–aggregate mix bear significant influence on the compressive strength of CHB's, both for those at age 14 and 28 days, respectively.
4. The mix ratio of cement and aggregates and the percentage of RH needed to obtain the compressive strength, fæ, value of at least 1,000 psi can be tabulated as follows:

A. CHB's containing PRH at age 14 days:

Mix Ratio	% RH	fć MPa(psi)
1:3	4	10.72 (1,555)
1:5	1	9.70 (1,407)
1:5	4	7.20 (1,043)

B. CHB's containing URH at age 14 days:
No CHB's containing any of the mix ratios nor any of percentages of RH's have fć ≥ 1,000 psi.

C. CHB's containing PRH at age 28 days:

Mix Ratio	% RH	fć MPa(psi)
1:3	4	11.39 (1,652)

D. CHB's containing URH at age 28 days:

Mix Ratio	% RH	fć MPa(psi)
1:3	1	8.64 (1,254)
1:5	2.6	7.30 (1,059)
1:5	1	7.05 (1023)

Recommendations

After a thorough analytical and experimental review, this study has come up with the following recommendations:

1. Percentage of Pulverized Rice Husks may be increased to a value greater than 4% when mixed with cement and aggregates at a ratio of 1:3 to determine the maximum amount.
2. Rice Husks may be used in pre–cast concrete decorative blocks and non-load bearing hollow block units.
3. Rice Husks may be burned to produce reactive ash, which can supplement Portland cement requirement.
4. Rice Husks may be used as additives or major aggregates in the production of bricks, blocks or particle–boards.
5. Rice Husks may be used as insulating materials in house construction, farm structures and cold–storage unit.
6. Rice Husks may serve as lightweight aggregates.

APPENDIX A

Statistical Equations for Compressive Strength

Sum of Squares Formula :

$SS_A = \Sigma y^2_{i\ldots}/bcn - y^2_{\ldots}/abcn$

$SS_B = \Sigma y^2_{.j..}/acn - y^2_{\ldots}/abcn$

$SS_C = \Sigma y^2_{..k.}/abn - y^2_{\ldots}/abcn$

$SS_{AB} = \Sigma \Sigma y^2_{ij\ldots}/cn - y^2_{\ldots}/abcn - SS_A - SS_B$

$SS_{AC} = \Sigma \Sigma y^2_{i\cdot k}/bn - y^2_{\ldots}/abcn - SS_A - SS_C$

$SS_{BC} = \Sigma \Sigma y^2_{.jk.}/an - y^2_{\ldots}/abcn - SS_B - SS_C$

$SS_{ABC} = \Sigma \Sigma \Sigma y^2_{ijk}/n - y^2_{\ldots}/abcn - SS_A - SS_B - SS_C - SS_{AB} - SS_{AC} - SS_{BC}$

$SS_E = \Sigma \Sigma \Sigma y^2_{ijk.}/n - y^2_{\ldots}/abcn$

$SS_T = \Sigma \Sigma \Sigma \Sigma y^2_{ijkl} - y^2_{\ldots}/abcn$

Mean Square Formula :

$MS_A = SS_A / (a-1)$

$MS_B = SS_B / b-1)$

$MS_C = SS_C / (c-1)$

$MS_{AB} = SS_{AB} / (a-1)(b-1)$

$MS_{AC} = SS_{AC} / (a-1)(c-1)$

$MS_{BC} = SS_{BC} / b-1)(c-1)$

$MS_{ABC} = SS_{ABC} / (a-1)(b-1)(c-1)$

$MS_E = SS_E/abc(n-1)$

F Statistics Formula :

F_A	=	MS_A / MS_E	F_B	=	MS_B / MS_E
F_C	=	MS_C / MS_E	F_{AB}	=	MS_{AB} / MS_E
F_{AC}	=	MS_{AC} / MS_E	F_{BC}	=	MS_{BC} / MS_E
F_{ABC}	=	MS_{ABC} / MS_E			

The value of F statistics is significant if F_O is less than $F_{\alpha, \upsilon 1, \upsilon 2}$

APPENDIX B

Mix Computation for CHB's With Rice Husks

a) For Cement – Aggregate Ratio of 1:3

Gross Vol. CHB	= (0.15 x 0.19 x 0.39)	= 0.011115 m^3
Vol. of 1 hole	= 3.1416$(0.05)^2$(0.19)	= 0.00149 m^3
Net Vol. CHB	= (0.011115 – 3 x 0.00149)	= 0.00664 m^3

- **@ 1% Rice Husks by Weight**

From Appendix A: Volume of One CHB = 0.00664 cu.m.

- **Mix proportion by Weight:**

Cement	=	40 kg		
Coarse	=	8 x 3	=	24 kg
Fine	=	32 x 3	=	96 kg
Water	=	40 x 0.3	=	12 kg

- **Absolute Volume of Materials**

Cement	=	40 / 3.15	=	0.0127 m^3
Coarse	=	24 / 2.68	=	0.0089 m^3
Fine	=	96 / 2.64	=	0.0363 m^3
Water	=	12 / 1	=	0.0120 m^3
		Total	=	**0.0699 m^3**

- **Materials Required per Batch mix**

Total Volume Required per batch mix			=	6(0.00664) m³
			=	0.03984 m³
Cement	=	40 (0.03984 / 0.0699)	=	22.798 kg
Coarse	=	24 (0.03984 / 0.0699)	=	0.678 kg
Fine	=	96 (0.03984 / 0.0699)	=	54.715 kg
R.H	=	0.01(13.678 + 54.715)	=	0.684 kg
Water	=	12 (0.03984 / 0.0699)	=	6.839 kg
		Total	=	**98.714 kg**

The process of computation is repeated, but the amount of rice husks will vary from 0.01 to 0.026 and 0.04 of the total aggregates. The summary of computations is tabulated in Tables2, 3, and 4. The equivalent result of the values of Loads applied in Tables 5 and 6 are shown in Tables 7 and 8 in MPa units.

***Table 2**. CHB Mix Design at 1% Rice Husks by Weight of Aggregates*

Components	Cement – Aggregate Mix Ratio		
	1:3	1:5	1:7
Cement	22.798	15.904	12.230
Coarse Aggregates	13.678	15.904	17.122
Fine Aggregates	54.715	63.616	68.489
Rice Husks	0.684	0.795	0.856
Water	6.839	4.771	3.669
Total	98.714 kg	100.990 kg	102.366 kg

***Table 3**. CHB Mix Design at 2.6% Rice Husks by Weight of Aggregates*

Components	Cement – Aggregate Mix Ratio		
	1:3	1:5	1:7
Cement	22.798	15.904	12.230
Coarse Aggregates	13.678	15.904	17.122
Fine Aggregates	54.715	63.616	68.489
Rice Husks	1.778	2.067	2.225
Water	6.839	4.771	3.669
Total	99.808 kg	102.262 kg	103.735 kg

***Table 4**. CHB Mix Design at 4% Rice Husks by Weight of Aggregates*

Components	Cement – Aggregate Mix Ratio		
	1:3	1:5	1:7
Cement	22.798	15.904	12.230
Coarse Aggregates	13.678	15.904	17.122
Fine Aggregates	54.715	63.616	68.489
Rice Husks	2.735	3.181	3.424
Water	6.839	4.771	3.669
Total	100.765 kg	103.376 kg	104.934 kg

APPENDIX C

Loads Applied in kN

***Table 5.** Loads Applied at age 14 days*

Cement-Aggregate Mix Ratio	CHB's Containing URH			CHB's Containing PRH		
	1%	2.6%	4%	1%	2.6%	4%
1:3 Ratio	177	222.5	165.5	240.5	239	354
	175	222.5	145	222	235	399
	183.5	227.5	157	235	224	371
1:5 Ratio	164.5	104	95.5	328.5	221.5	268
	170.5	105	86	372	241	227.5
	180	104.5	110	317	223	259
1:7 Ratio	116	33	72	208.5	232	158.5
	126	33	71	187.5	220	132.5
	126	42.5	62	197	225	160.5

***Table 6.** Loads Applied at age 28 days*

Cement-Aggregate Mix Ratio	CHB's Containing URH			CHB's Containing PRH		
	1%	2.6%	4%	1%	2.6%	4%
1:3 Ratio	298.5	268.5	194	165.5	208.5	372.5
	282	231	141	191	203.5	358.5
	325.5	266	161.5	249	283.5	463
1:5 Ratio	285	144	102	224.5	199.5	211
	232.5	135.5	147.5	245	270.5	219
	221.5	138	113.5	221	206	268
1:7 Ratio	175	62	84.5	249.5	239.5	152
	172	48	79.5	214	180.5	156
	160	67.5	77.5	221.5	191.9	156.5

Table 7. *Equivalent fœ in MPa at age 14 days*

Cement-Aggregate Mix Ratio	CHB's Containing URH			CHB's Containing PRH		
	1%	2.6%	4%	1%	2.6%	4%
1:3 Ratio	5.07	6.37	4.74	6.88	6.84	10.13
	5.01	6.37	4.15	6.35	6.73	11.42
	5.25	6.51	4.49	6.72	6.41	10.62
1:5 Ratio	4.71	2.98	2.73	9.40	6.34	7.67
	4.88	3.01	2.46	10.64	6.90	6.51
	5.15	2.99	3.15	9.07	6.38	7.41
1:7 Ratio	3.32	0.94	2.06	5.97	6.64	4.54
	3.61	0.94	2.03	5.37	6.30	3.79
	3.61	1.22	1.77	5.64	6.44	4.58

Table 8. *Equivalent fœ in MPa at age 28 days*

Cement-Aggregate Mix Ratio	CHB's Containing URH			CHB's Containing PRH		
	1%	2.6%	4%	1%	2.6%	4%
1:3 Ratio	8.54	7.68	5.55	4.74	5.97	10.66
	8.07	6.61	4.04	5.47	5.82	10.26
	9.32	7.61	4.62	7.13	8.11	13.25
1:5 Ratio	8.16	4.12	2.92	6.43	5.71	6.04
	6.65	3.88	4.22	7.01	7.74	6.27
	6.34	3.95	3.25	6.33	5.90	6.11
1:7 Ratio	5.01	1.77	2.42	7.14	6.85	4.35
	4.92	1.37	2.28	6.12	5.17	4.52
	4.58	1.93	2.22	6.34	5.49	4.48

APPENDIX D

Analysis of Variance

***Table 9.** Analysis of Variance for Compressive Strength at age 14 days*

Source of Variance	Sum Of Squares	Degrees of Freedom	Mean Square	F-Ratio	P-value
MAIN EFFECTS					
A: Mix Ratio	75.4551	2	37.7276	*284.30	0.0001
B: Amount of RH	8.10055	2	4.05027	*30.52	0.0001
C: Type of RH	157.389	1	157.389	*1186.02	0.0001
INTERACTIONS					
AB	31.0741	4	7.76852	*58.54	0.0001
AC	5.61498	2	2.80749	*21.16	0.0001
BC	5.95858	2	2.97929	*22.45	0.0001
ABC	35.5051	4	8.87628	*66.89	0.0001
RESIDUAL	4.77733	36	0.132704		
TOTAL(corr.)	323.875	53			

*▶ Significant at α = **0.05**

***Table 10.** Analysis of Variance for Compressive Strength at age 28 days*

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	P-value
MAIN EFFECTS					
A: Mix Ratio	89.2881	2	44.6441	*63.99	0.0001
B: Amount of RH	17.5773	2	8.78867	*12.60	0.0001
C: Type of RH	40.1073	1	40.1073	*57.49	0.0001
INTERACTIONS					
AB	16.5042	4	4.12604	*5.91	0.0009
AC	4.88044	2	2.44022	*3.50	0.0409
BC	47.4963	2	23.7481	*34.04	0.0001
ABC	43.1620	4	10.7901	*15.47	0.0001
RESIDUAL	25.1144	36	0.697623		
TOTAL(corr.)	284.128	53			

*▶ Significant at α = **0.05**

Tables 9 and 10 presents the analysis of variance for compressive strength results from Tables 7 and 8. All Factors A, B, C and their interactions AB, AC, BC, ABC, have P-values below 0.05, and thus, statistically significant at the 95.0% confidence level. This means that, the presence of the mix ratio, amount of RH and type of RH, significantly affect the compressive strength of the load-bearing CHB's. The results on Tables 9 and 10 were computed using the Statlets.exe software.

References

Abrams, Daniel P. (1994), *Masonry in the Americas*, American Concrete Institute, USA.

Lauricio, Feliciano M. (1987), *Technology Manual on Rice–Husk Ash Cements*, Philippines

Moavenzadeh, Fred. (1990), *Concise Encyclopedia of Building and Construction*, Great Pergamon Press plc., Britain.

Montgomery, Douglas C. (1991), *Design and Analysis of Experiments*, John Wiley and Sons Inc., USA.

Polprasert, Chongrak (1996), *Organic Waste Recycling*, John Wiley & Sons Ltd., England.

Sajorda, Q.A. (1996), *Constrcution Master Specification for Miscellaneous Buildings*, The Elasto Marketing Corporation, Philippines.

Schneider, R.R, and W.L Dickey (1994), *Reinforced Masonry Design*, Prentice–Hall Inc., New Jersey.

Smith, Ronald C. (1973), *Materials of Construction*, McGraw – Hill Inc., USA.

Swamy, R.N. (1988), *Natural Fibre Reinforced Cement and Concrete*, Blackie and Son Ltd., London.

Telford, Thomas (1989), *Durable Concrete Structures (Design Guide)*, Thomas Telford Services Ltd., London.