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Study of Properties of Light Weight Concrete made Using Local Industrial by Products

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Abstract

The paper presented here is intended to make an investigation of the use of locally available materials in and around the Bellary district to make lightweight concrete (lwc). The district has harbored many steel and pig iron industries and brick casting yards which can provide raw materials for making lightweight concrete. The materials which are used in the present study are bloated slag (foamed slag), hard burnt brickbats, fly ash, ground granulated blast furnace slag (ggbs), and OPC Cement. Another abundantly, economically available material is Rice husk from local rice mills. This material, when used as an ingredient it helps to fulfill the engineering requirements of lightweight concrete. The fresh concrete proportions are fixed to give a slump of 25 – 50 mm. W/p ratio is used between 0.5 – 0.7 to achieve the required slump. The desirable engineering properties of lwc, such as unit weight and compressive strength, are arrived at by keeping some ingredients constant. And the rice husk is considered as one of the variables. In addition, modeling of the variables is made in order to know the relationships between important critical properties of lightweight concrete. It is possible to produce lightweight concrete economically as the ingredients, bloated slag, brickbats, and rice husk are abundantly available in the place of study. The study indicates the combination of materials such as fly ash, ggbs, bloated slag/brickbats, and rice husk yielded a lot, with densities varying from 1200 a 1400 kg/m3 and compressive strength varying in the range 7 to 11.21 N/mm2.

Keywords*: Lightweight aggregates, bloated slag, brickbats, rice husk, fly ash, ggbs, modeling, the goodness of fit.*

I. Introduction

The ever-demanding different civil constructions need advanced technology and engineering principles. To optimize technological aspects, technocrats have always searched for alternate construction materials. Lightweight concrete is one offshoot that emerged long back through the modification of the conventional concrete.

It is a well-known fact that the largest construction material consumed by the construction industry is none other than concrete. The concrete, which is less known in practice, even though it has existed for a long time, in civil engineering, is the “Lightweight concrete.”

On the contrary, there is another type of lwc, generally called lightweight cellular concrete (CLC), also called foamed concrete. It is quite different in, the technology which is based on what is known as metal stable foam formation due to a chemical reaction between ingredients. It is also important that, in CLC designs, there is a dire need to control the % of air entrainment given to the fresh concrete mix. As % air content varies, the unit weight and also compressive strength varies. Hence the measurement of air entrainment is one of the key factors in the design of lightweight or air-entrained concrete. Usually, this is done by using the following methods. These are the Pressuremeter test, Roll-O-meter test, and unit weight method. Even air content in the hardened lwc also can be determined from first principles. M.L.Gambhir1et al and Ken Hover4 et al. have explained in detail methods to estimate entrained air in fresh concrete.

Lightweight concrete, as defined by M. S. Shetty et al. 2, is the concrete possessing an oven-dried density between 800 to 1000 Kg/m3 to up to 2000 kg/m3. Hence, in order to reach the densities, stated above the materials used are t different from the normal concrete. Though there isn’t exact demarcation, between such aggregates, in different parts of the world, different lightweight aggregates (LWA) are used. Commonly used materials all over the world are bloated slag, expanded clay, shale, pumice stone, diatomite, brickbats, etc. Along with these aggregates, other auxiliary materials such as Rice husk, cinder, fly ash, ggbs, sawdust, or any suitable agricultural by-products can also be used in making lwc.

In comparison with lightweight concrete, usually normal concrete weighs above 2000 Kg/m3, but there is no clear boundary for lwc in terms of its unit weight, as it differs from place to place and country to country. Many civil constructions like the casting of slabs, columns, beams, panels, foundations, etc., use conventional concrete. As we are aware, this concrete has a few commonly adopted ingredients such as cement, fine aggregate, coarse aggregate, admixtures, and some pozzolans, at some suitable ratio so as to meet constructional requirements. But such concrete is always found heavy with unit weight varying between 2200 Kg/m3 to 2600Kg/m3 depending on the properties of materials and their proportions. Such concrete always increases the load on the structure and makes the

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columns and beams to be designed accordingly. Especially when the structure to be placed on loose or weak soils, then the foundation design becomes a difficult and tedious job for civil engineers. Also, it may force us to choose deep foundations depending on the size and type of soil at the site. The use of LWC can be a right substitute for normal concrete in such cases. By using lwc, the weight of wall partitions reduces, and accordingly, the weight of the whole structure decreases. The use of lwc is more beneficial at places where structures are placed in zones where earthquake forces are more. The inertial earthquake forces get reduced in proportion to the reduction in the total weight of the structure.

To backfill the excavations for roads, backfilling trenches and patching up works for roads, etc., the use of lwc is most desirable. In all these situations, it is possible to plug these voids using lwc construction material, which is stable and able to resist prevailing external forces or loads. It is also possible to reduce a considerable quantity of percentage of steel as the weight on structural members gets reduced. Further, if lwc is adopted for long-span bridges, one can strike a great reduction in the dead to live load ratio if designed as structural concrete. Lightweight concrete is the concrete made with selected or chosen materials, wherein this concrete can be either non-structural or structural. The structural concrete may have Compressive strengths varying between M15 to M20. A structural LWC may have strength varying between M20 to M40. Either Th. Dawood5 et al. have obtained in their work on structural lwc strengths up to M20 with a unit weight of concrete between 1900 to 2000 Kg/m3.

The following are the various applications of lightweight concrete that are used in the civil engineering field.

- Cellular concrete blocks
- Precast floor and roof panels.
- Partition walls
- Insulation claddings.
- Precast composite wall.
- Parapet walls
- Filling for road cuttings, excavations, and backfilling trenches.
- Precast beams.
- Good insulator of sound
- Good barrier for heat and thermal energy etc.

II. Materials and Methods

In the present pursuit of making lightweight concrete blocks, the following materials are used.

1. Cement (OPC 43 Grade)
2. Fly ash (From a nearby BTPS Thermal plant)
3. Ground granulated blast furnace slag
4. Stone grit
5. Rice husk (from rice mills)
6. Air entraining agent (Micro-air-720)
7. Lightweight aggregates:
   (a) Bloated slag. (Foamed slag) (from iron industries)
   (b) Over burnt brickbats. (from local brick kilns)

All these materials are thoroughly analyzed in the laboratory for physical and other mechanical properties.

Table 1. Physical and Mechanical Properties of Materials.

SL No	Material	Material property		Average results
1	Cement	Specific gravity		3.15
2	"	I.S.T.		50 minutes
3	"	F.S.T.		285 minutes
4	"	C.S. at 7 Days		32N/mm2
5	Fly Ash	Specific gravity		2.5022
6	GGBS	Specific gravity		2.92
7	Bloated Slag	Bulk Specific gravity		1.7-18
8	Brickbats	Bulk Specific gravity		1.4-1.5
9	Rice Husk	Specific gravity		1.06
10	Bloated slag	Fineness Modulus.		9.16
11	Brickbats	Fineness modulus		9.16
12	B.Slag	10 % Fines value		Approx. 100KN
13	Bloated slag	Water absorption		16.34
14	Brickbats	Water absorption		12.11
15	Cubes	4.672(before)	Avg 10.9	9.93
				14.11
		4.351(before)		8.92
		4.906(before)		
15	Bloated slag	Loose bulk density		655.6 Kg/m3
		Compacted bulk density		795.8 Kg/m3
16	Brickbats	Loose bulk density		735.63 Kg/m3
		Compacted bulk density		907.03Kg/m3

Table 2. Sieve Analysis for Bloated Slag/ Brick Bats

Sieve Size	Weight Retained (gm)	Cumulative Weight (gm)	% Cumulative Weight	Cumulative Passing
25 mm	-	-	-	100
20 mm	2180	2180	22	78
16 mm	2772	4952	51.8	48.2
10 mm	2124	7076	74	26
8 mm	872	7948	83.15	16.85
6.3 mm	698	8646	90.45	9.55
4.75mm	454	9100	95.2	4.8
2.36mm	-	-	100	0
1.18mm	-	-	100	0
600micron	-	-	100	0
300micron	-	-	100	0
150micron	-	-	100	0

III. Experimental Programme

The Total work done is divided into the following stages.

- Selection of materials
- Fresh concrete studies
- Hardened concrete studies

The raw materials for LWA selected are bloated slag and brickbats for the purpose of casting cubes and blocks. Other materials selected are Fly ash, GGBS, as these are available at very low prices and are also easily available in the area under study. The LWA material brought from the field is in the form of hard lumps and is very hard, required to be crushed by applying mechanical forces.

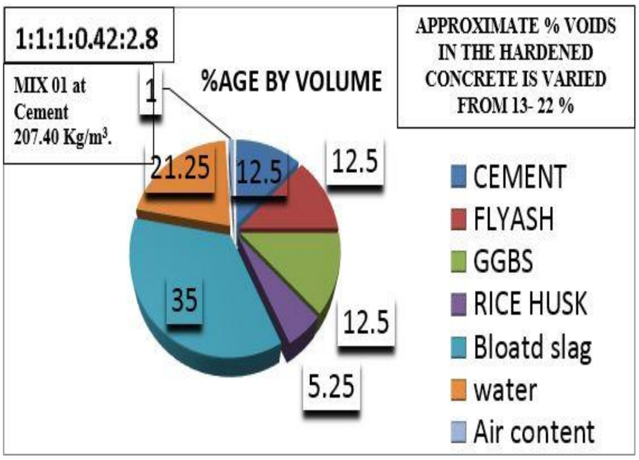
Hence it becomes necessary to crush them and to reduce them to the required size and grading. The maximum size of the aggregates is adopted as 25 mm, and the lower size is fixed at 4.75 mm. six cubes are cast and cured for 7 and 28 days, respectively, for each proportion, and the average is worked out. Later they are tested at the end of the curing period, and results are recorded.

A. Trial Mix Proportions

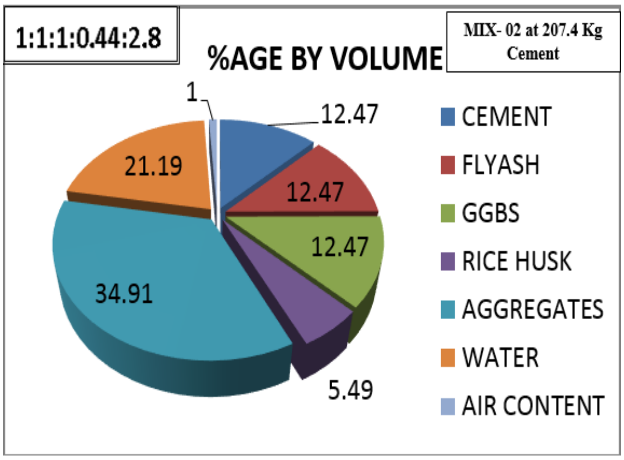
The literature studies indicate, there are no such mixed design methods established in the field but primarily depend on the type of lightweight aggregate used to make the concrete. Also, the properties of lightweight aggregates vary geographically throughout the world. Hence, there is no standardized mix design procedure available to make lwc. It further depends on whether we are designing structural or non-structural lightweight concrete. Hence due to all these reasons, Lightweight concrete mix proportions are usually established by trial mixes. Proportioning was made considering the volume or weight of ingredients per m3 basis. But in some countries, some guidelines are given based on specific types of LWA used. Trial mixes are made in the laboratory by deciding on an absolute volume of individual ingredients. An air-entrainer Micro- Air-720 was used to improve the workability of the mix. One of the common problems faced while deciding about proportions is due to the porosity of LWA. As they are highly porous, they tend to absorb water, and hence they may be needed to be soaked in water before mixing with other ingredients. With 1.5 % of the air-entrained, the fresh lwc gave slump between 25- 40 mm, with hand compaction.

Hence, though the slump value is low, the mix is not stiff, and there is no problem compacting the concrete by hand. Hence, hand compaction is adopted in the present study. Three levels of cement content are chosen in order to get strengths in the range of M5 to M10 or M15 and to make it qualify for non-structural lightweight concrete. Usually, structural we will have strength above M20. (ACI Specifies M17). The cement content was fixed around 210.0Kg, 300.0 Kg, and at 325.0 Kg/m3 in order to get different compressive strengths. Rice husk percentages are also varied, ranging between 5 – 12 % by volume. But the actual rice husk percentages after calculation are 6.7 %,7.05 %,7.9 %, 8.33 %, 8.66 %, 9.1%, 9.2 %, 9.5 %, 10.2 %, 11.67 % for different mixes As proper air entrainment measuring instrument was not available, the porosity of the concrete cubes, are measured, using theoretical formulas.

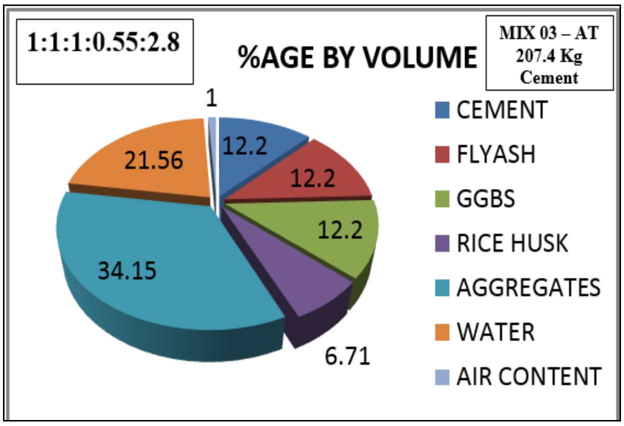
a) Approximate Trial Proportions for Brick Bats and Bloated Slag:



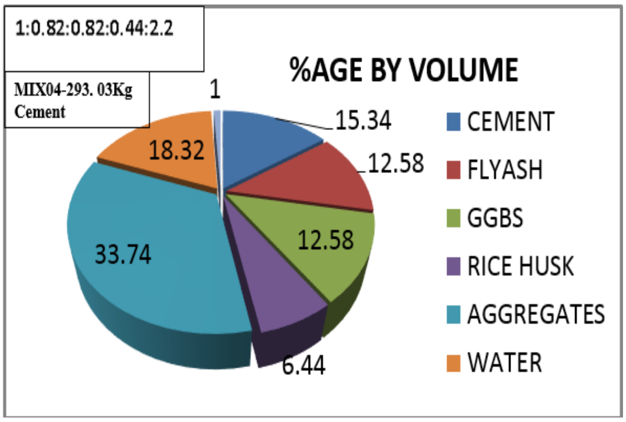
(a) 5.25% RH



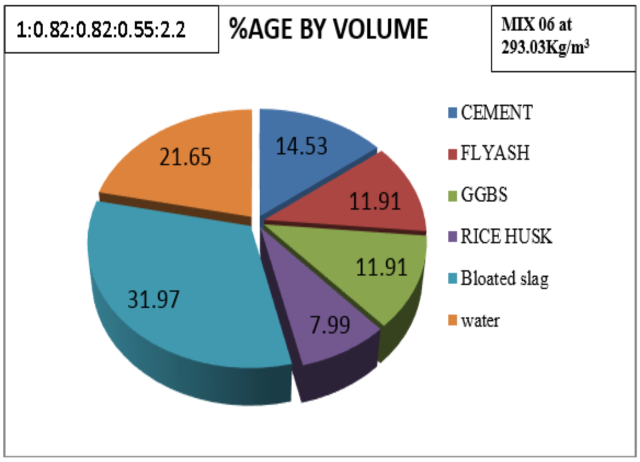
(b) 5.49% RH



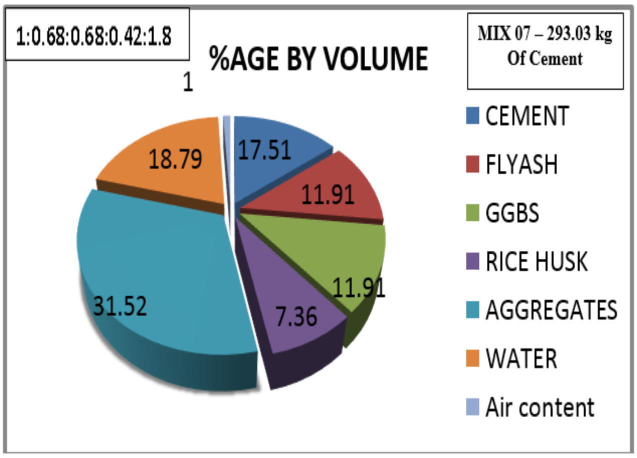
(c) 6.71% RH



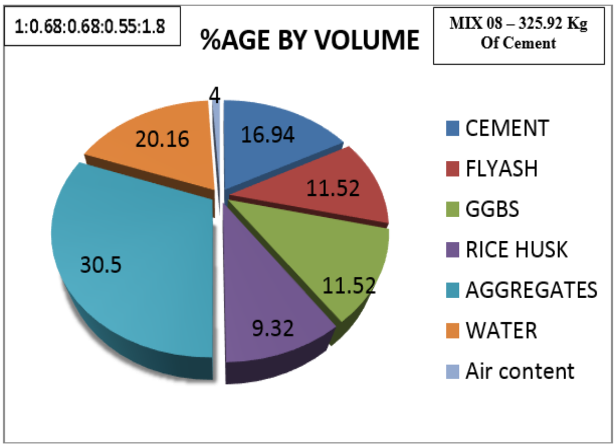
(d) 6.44% RH



(e) 7.99% RH



(f) 7.36% RH



(g) 7.36% RH

Fig. 1. Pie chart with % of ingredients for a typical mix at (a) – (g)

B. Fresh Concrete Studies

In order to study the workability behavior of the fresh lwc concrete mix, slump values are determined after adding an air-entraining agent, as said before. The concrete to show good compatibility behavior, sufficient powder in the form of fly ash and ggbs, are added. But to keep the unit weight of lwc low, Rice husk is added at different percentages, which gave good homogeneity, cohesiveness, and workable character to the mix. The slump was finalized, ranging between 25 – 50 mm, and cubes are cast. The details of various mix proportions and their respective slump values recorded are tabulated below in Tables 3 and 4. Though the mix showed low slump values, the air-entraining agent added made the mix workable, and hand compaction is adapted to compact concrete fully, avoiding vibration for compaction.

Table 3. Fresh Concrete Studies Using Overburnt Brick Bats.

Overburnt Brick Bats Studies											
Proportion	**Cement Kg/m3**	**Fly Ash Kg/m3**	**GGBS Kg/m3**	**Rice Husk Kg/m3**	**Brick Bats Kg/m3**	**Water in Kg/m^3**	**Air entraining Agent % by weight of Cement**	**w/p**	**w/c**	**Slump mm**	**% RH**
1:1:1:0.42:2.8	207.40	207.40	207.40	87.10	580.72	369.172	1.5	0.6	1.78	35	5.25
1:1:1:0.44:2.8	207.40	207.40	207.40	91.25	580.72	369.172	1.5	0.6	1.78	40	5.49
1:1:1:0.55:2.8	207.4	207.40	207.40	114.07	580.72	383.7	1.5	0.61	1.85	35	6.71
1:0.82:0.82:0.42:2.2	293.03	240.28	240.28	123.073	644.666	369.21	1.5	0.47	1.26	35	6.44
1:0.82:0.82:0.44:2.2	293.03	240.28	240.28	128.93	644.666	419.03	1.5	0.54	1.43	40	6.56
1:0.82:0.82:0.55:2.2	293.03	240.28	240.28	161.166	644.666	419.03	1.5	0.54	1.43	40	8.06
1:0.68:0.68:0.42:1.8	325.92	221.62	221.62	136.88	586.65	368.28	1.5	0.48	1.13	35	7.36
1:0.68:0.68:0.44:1.8	325.92	221.62	221.62	143.40	586.65	368.28	1.5	0.48	1.13	40	7.68
1:0.68:0.68:0.55:1.8	325.92	221.62	221.62	179.25	586.65	368.28	1.5	0.48	1.13	40	9.42

Table 4. Fresh Concrete Studies Using Bloated Slag

Bloated Slag Studies											
Proportion	**Cement Kg/m3**	**Fly Ash kg/m3**	**GGBS kg/m3**	**Rice Husk kg/m3**	**Slag kg/m3**	**Water in Kg/m3**	**w/p**	**w/c**	**Air entraining Agent % by Weight of Cement**	**Slump mm**	**% RH**
1:1:1:0.42:2.8	207.40	207.40	207.40	87.10	580.72	344.28	0.55	1.66	1.5	30	5.33
1:1:1:0.44:2.8	207.40	207.40	207.40	91.25	580.72	325.61	0.52	1.57	1.5	20	5.63
1:1:1:0.55:2.8	207.40	207.40	207.40	114.07	580.72	344.28	0.55	1.66	1.5	40	6.87
1:082:0.82:0.42:2.2	293.03	240.28	240.28	123.073	644.666	392.66	0.50	1.34	1.5	30	6.36
1:082:0.82:0.44:2.2	293.03	240.28	240.28	128.93	644.666	378.08	0.48	1.29	1.5	30	6.7
1:082:0.82:0.55:2.2	293.03	240.28	240.28	161.166	644.666	436.61	0.56	1.49	1.5	35	7.99
1:0.68:0.68:042:1.8	325.92	221.62	221.62	136.88	586.65	368.29	0.48	1.13	1.5	35	7.36
1:0.68:0.68:0.44:1.8	325.92	221.62	221.62	143.40	586.65	384.58	0.5	1.18	1.5	38	7.61
1:0.68:0.68:0.55:1.8	325.92	221.62	221.62	179.25	586.65	387.84	0.50	1.19	1.5	40	9.32

C. Hardened Concrete Properties

After the fresh concrete studies, six cubes are cast for each proportion and tested at the end of 7 and 28 days. The average of six cubes is noted and recorded in the table 5 and 6 shown below:

Percentage voids in the hardened concrete cubes are computed by the formula:

$$\% \text{ voids} = \frac{\text{Actual bulk specific gravity}}{\text{Theoretical bulk specific gravity}}$$

Table 5. Hardened Concrete Properties With Overburnt Brick Bats.

Proportion	Cube Weights Max-Mini Kg.	Average Unit Weight of Concrete kg/m^3 (Equilibrium Density)	Average 7days Compressive Strength N/mm^2	Average 28days Compressive Strength N/mm^2	% Voids	Cost per m^3 Rs.
1:1:1:0.42:2.8	4.82- 4.47	1394	7.55	8.13	13.20	2698.90
1:1:1:0.44:2.8	4.85 - 4.28	1325	7.33	8.44	18.50	2703.05
1:1:1:0.55:2.8	4.29 - 4.16	1264	5.55	7.11	21.25	2726.05
1:0.82:0.82:0.42:2.2	4.60-4.26	1322	8.88	9.77	20.34	3548.41
1:0.82:0.82:0.44:2.2	4.63-4.29	1311	8.22	9.11	18.34	3554.27
1:0.82:0.82:0.55:2.2	4.57-4.26	1305	7.33	8.44	20.20	3586.51
1:0.68:0.68:0.42:1.8	4.83-4.40	1341	9.99	10.20	19.70	3743.15
1:0.68:0.68:0.44:1.8	4.57-4.31	1316	9.55	9.70	19.81	3739.67

Table 6. Hardened Concrete Properties With Bloated Slag

Proportion	Cube Weights Max-Mini Kg.	Average Unit Weight of Concrete kg/m^3 (Equilibrium Density)	Average 7days Compressive Strength N/mm^2	Average 28days Compressive Strength N/mm^2	% Voids	Cost per m^3 Rs.
1:1:1:0.42:2.8	4.56 - 4.42	1339	7.65	9.20	17.55	2698.90
1:1:1:0.44:2.8	4.53-4.33	1316	7.11	8.15	19.21	2703.05
1:1:1:0.55:2.8	4.48-4.30	1299	7.00	8.50	19.13	2726.05
1:0.82:0.82:0.42:2.2	4.97-4.71	1422	9.75	9.80	13.08	3548.41
1:0.82:0.82:0.44:2.2	4.68-4.41	1347	8.88	9.00	17.82	3554.27
1:0.82:0.82:0.55:2.2	4.67-4.22	1307	8.00	8.80	18.10	3586.51
1:0.68:0.68:0.42:1.8	4.71-4.56	1380	9.70	11.21	16.06	3743.15
1:0.68:0.68:0.44:1.8	4.83-4.47	1355	8.00	9.88	16.02	3739.67

IV. Results and Mathematical Modelling

The following methodology is adopted in developing a mathematical model for obtaining the relationship between various variables. The variables chosen in the project are Unit weight, % of Rice husk, Compression strength, etc. By plotting between these variables, the mathematical models are developed.

Using standard software, the coefficient of determination"R2 " (Adjusted) is found for each plot. The R2 value indicates the goodness of fit, as the value being higher (nearer to one) implies, the fitted model or regression is good, and unknown values can be read from the plotted curve if necessary. Even though there are several methods available to fit a set of data, curve fitting is done considering linear variation between the dependent and independent variables.

1. Linear equation
2. Power form equation.
3. Poly fit modeling.

Statistical Equations Used to Plot, the Model

Form of the linear equation

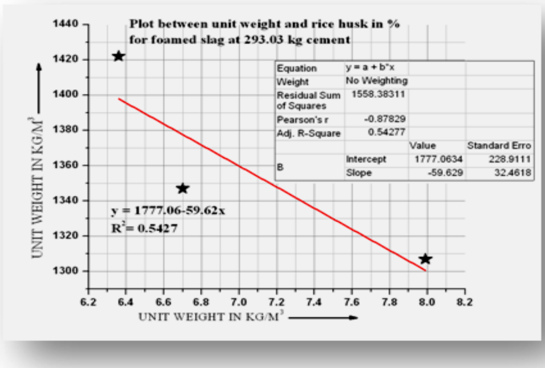
1. y=a+bx (y and x are variables along the y and x-axes, respectively)

Form of the power form equation

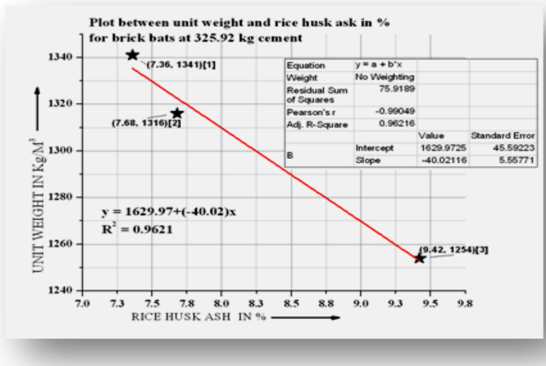
2. z=a*(b)xx*(c)y Where z= the parameter along Y-axis.
3. Which is likely to be a non-linear or a curve type.

A. Regression analysis of the Results

ANALYSIS FOR FOAMED SLAG

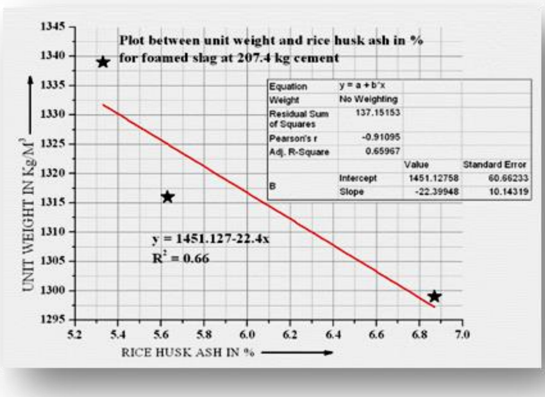


(i)

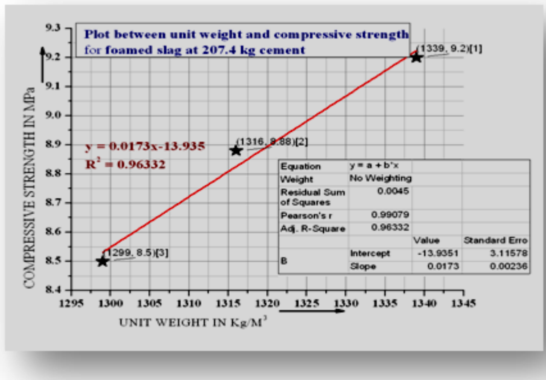


(v)

Fig. 3. Analysis For Analysis for Brick Bats(iv)&(v)



(ii)



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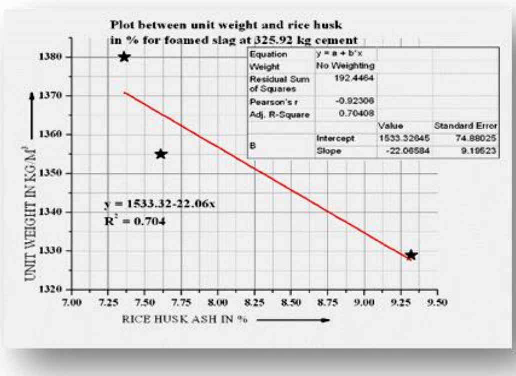

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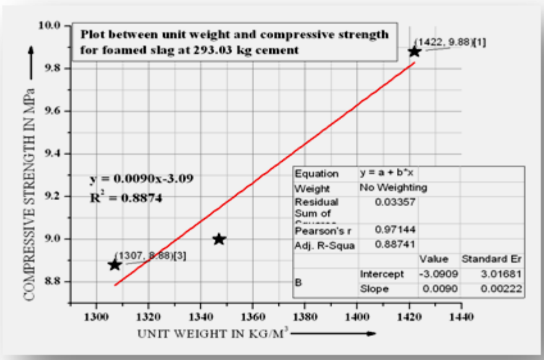
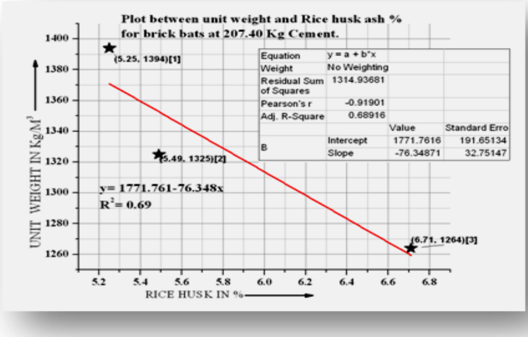
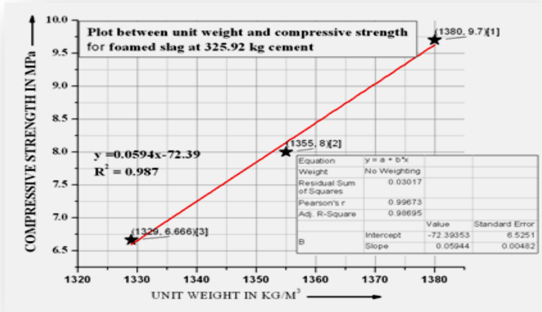


(vii)

Fig. 2. Analysis For Foamed Slag, (i),(ii)&(iii)

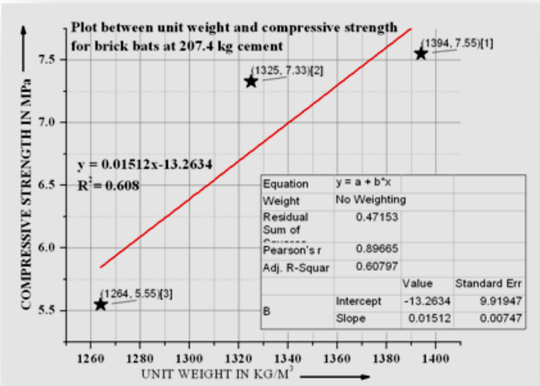


(iv)

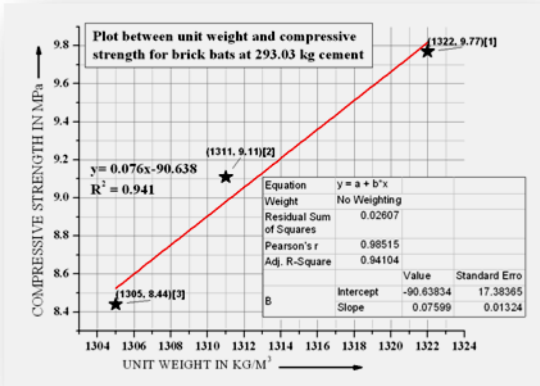


(viii)

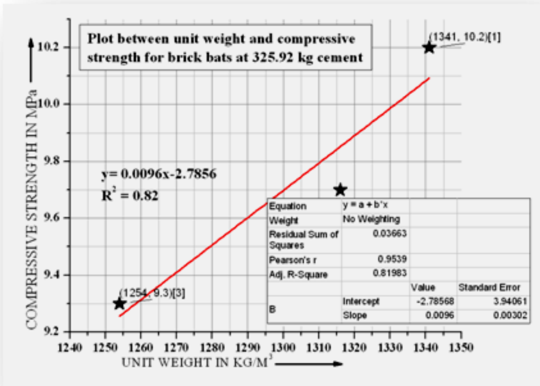
Fig. 4. Relatioships between Unit Weight and Compressive Strength for Foamed Slag as LWA -(vi), (vii) & (viii)



(ix)



(x)



(xi)

Fig. 5. Relationships between Unit Weight and Compressive Strength for Brick Bats as LWA -(ix), (x) & (xi).

Note: It needs to be noted that the R2 values are significantly low for Figures 1 & 2 because, as explained before, the % ingredients calculated are approximate, and no instrument was used to compute % of rice husk and air content. The final computations made on hardened concrete cubes are the facts that are measured physically and gave accurate results and are correlated with high R2 values for plots between unit weight and compression strength, as shown in Figures 4 & 5.

Table 7. As Per I.S. 2185 (Part IV), The Compressive Strength Chart for LWC for Foamed Concrete Only (CLC, Cellular Light Weight Concrete)

Density	Grade	Compressive strength N/mm^2		Water absorption %
		Min	Max	
800	G-2.5	2	2.5	12.5
1000	G-3.5	2.8	3.5	12.5
1200	G-6.5	5.2	6.5	10
1400	G-12	9.0	12	10
1600	G-17.5	14.5	17.5	7.5
1800	G-25	22	25	7.5

Fig. 6. A Moulded Block of Size 6” X8” X12” and With LWC Cubes.

B. Cost Analysis

Table 8. Cost Analysis Per Block (6” X8” X12”) Using Brick Bats.

Sl No.	Materials	Quantity In Kgs	Cost Price In Rs.	Total Cost In Rs. (Including Tax)
1	Cement	1.50	9.6	14.10 (+1.7) =15.80
2	Flyash	1.50	0.5	
3	GGBS	1.50	2.0	
4	Brickbats	4.20	0	
5	Rice Husk	0.825	1.0	
6	Labour charges	Lumpsum	1.0	
		Grand Total In Rs	14.10	

Table 9. Cost Analysis Per Block (6" X8" X12") Using Bloated Slag

Sl No.	Materials	Quantity In Kgs	Cost Price In Rs.	Total Cost In Rs. (Including Tax)
1	Cement	1.50	9.6	14.10 (+1.7) =15.80
2	Flyash	1.50	0.5	
3	GGBS	1.50	2.0	
4	Bloated Slag	4.20	0	
5	Rice Husk	0.825	1.0	
6	Labour charges	Lumpsum	1.0	
		Grand Total In Rs	14.10	

V. Conclusions: General

1) From the graphs, we can conclude that as the amount of Rice Husk increases, the unit weight of concrete decreases and strength decreases.
2) There is also an increase in compressive strength with an increase in unit weight
3) The cost of the blocks, as per our study, works out to be 16Rs, but the cost of a similar block from the market survey is 33Rs. Therefore % reduction in cost in comparison to market price is 52%.
4) Labor wages and transportation can be considerably smaller to transport the lightweight bricks/blocks.

For Brick Bats

5) The Brickbats also show highly promising results for making bricks and blocks using lightweight concrete technology. Over burnt brickbats are commonly available in most brick casting yards and can be a continuous source of raw material.
6) Achieved a lightweight concrete of unit weight 1264 Kg/m3 for 8.6 % of Rice Husk in 207.4 Kg/m3 of cement with brickbats. It is 48% less than conventional concrete by weight, and the compression strength is 5.55 MPa for 7 days and 7.11MPa for 28 days.
7) The maximum 28 days compression strength achieved is in the range 9.0-10MPa for cement content of 325Kg/m3.

For Bloated Slag

8) The bloated slag proves itself to be used as a good lightweight aggregate for making lwc. It is also available in large quantities from iron plants.
9) Achieved a lightweight concrete of unit weight 1299 Kg/m3 for 8.6 % of Rice Husk in 207.4 Kg/m3 of cement with brickbats. It is 49.9% less than conventional concrete, and the compression strength being 7.00 MPa for 7 days and 8.MPa for 28 days, which is satisfactory for most general and day-to-day constructions.
10) The maximum 28 days compression strength achieved is in the range of 10-11 MPa for cement content of 325Kg/m3

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[6] ACKNOWLEDGEMENT: Project Sponsored by KSCST, Indian Institute of Science, Bangalore, Karnataka.