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Engineering

EFFICIENT DESIGN OF FALG BRICKS USING TAGUCHI APPROACH

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ABSTRACT Building materials are the keystones for construction industry. Some building materials are in the form of building units such as bricks, concrete blocks and tiles. In India, conventional red clay bricks causes soil related issues which finally affect the environment. Alternatively, fly ash has advantages in its performance and environmental friendliness. Considering, this paper shows the optimal mix proportion for the FALG bricks. Taguchi design methodology was designed using a L9 orthogonal array with four control factors at three levels each. The effect of compressive strength and water absorption are analysed using mean response data and ANOVA techniques. Analysed results gives the maximum compressive strength of 22.612 Mpa. The optimal parameters were determined using minitab and the predicted compressive strength is 46.66 Mpa with 95% confidence level. For the same optimal trail, field value obtained is 28.741 Mpa. The deviations within the predicted and field value shows the interactions between the control factors. Hence considering the interactions, Response Surface Methodology shall be adopted for the optimal design of fly ash bricks.

KEYWORDS : FALG Bricks, Taguchi Design, Compressive Strength, ANOVA

INTRODUCTION:

Economical and eco-friendly brick manufacturing plays a major role and nowadays fly ash bricks have a unique place in the construction industry. Reasons for this steep growth of fly ash are 1) reduces the carbon foot prints and the external heat energy required when compared to the conventional clay bricks. 2) Availability of raw materials is cheaper since it is a by-product from thermal power plants. In India, the annual generation of fly ash as in year 2016-17 as per Central Electricity Authority (CEA) was 169.25 million tonne and utilization was 107.1 million tonnes (63.28 %). Ministry of Environment, Forests and climate change has taken initiative in September 1999, which was subsequently amended in 2003, 2009 and 2016 stated that "Every construction agency engaged in construction of buildings within a radius of 300 kms from coal or lignite based thermal power plant, shall use only fly ash based products for construction, such as cement or concrete, fly ash bricks/blocks/tiles or clay fly ash bricks etc., in every construction project" [2]. Incorporation of fly ash in concrete increases the compressive strength and durability properties. Codal provisions are also developed by Government to increase the utilization of fly ash. Researches on fly ash bricks brings out the usage of fly ash and its properties [9 – 12]. However considering the compressive strength, lime is used as an additive. The reaction between the lime and fly ash is slow at normal environmental conditions which introduces the use of gypsum in the fly ash bricks [5]. The main purpose of the work is to explore each of the constituent variations and M sand is also introduced in effect of river sand and the output parameters compressive strength and water absorption are studied. Studies on optimization of fly ash bricks by considering the input parameters are important. Usual approach of full factorial method leads to numerous trials and it is practically difficult. This made an alternative way to optimize using Taguchi's design method which is based on orthogonal array (OA) approach.

Materials:

Fly ash:

Fly ash is a fine powder that is a by-product of coal combustion in thermal power plants and consists mainly of SiO_2, Al_2O_3, Fe_2O_3, CaO and some other impurities. According to ASTM C 618 -17a fly ash are classified as class N, class F and class C. It belongs to class N and F if Silicon dioxide + Aluminium oxide + Iron oxide should be minimum 70 % and it belongs to class C if Silicon dioxide + Aluminium oxide + Iron oxide should be minimum 50 %. Usually class C fly ash exhibits the cementitious and pozzolanic properties while class F fly ash exhibits only pozzolanic properties [4]. Fly ash is used as mineral admixture in concrete because it transforms the calcium hydroxide into calcium silicate hydrate gel which decides the quality of concrete [7]. This property made the demand of fly ash utilization in concrete. In this study, fly ash is collected from Neyveli Lignite Corporation and the chemical composition is shown in table 1 [3]. From this, the fly ash belongs to class F since the combination of Silicon dioxide; iron oxide and aluminium oxide have a value of 82.27 % (> 70 %)

Table 1: Chemical Composition of fly ash

Chemical	Analysis (%)
MgO	4.76
CaO	6.32
Silicate	63.87
Alumina	10.80
Fe2O3	7.60
Loss on Ignition	6.63

Lime:

Lime is one of the binding materials used widely in ancient periods. Since the class F fly ash is used which has less CaO content, lime is used [5]. Usually lime cementitious material can be classified as hydraulic lime and non-hydraulic lime. Non hydraulic lime has 95 % of $CaCO_3$, higher the percentage of calcium carbonate purer the lime. It gets sets when it is exposed to environment by absorbing CO_2 and the setting time is slow. Hydraulic lime has calcium carbonate and impurities of clay and sets under water. They have good water proofing property and prevent subsoil dampness in floors and walls. The hydraulic lime is extremely reactive with water and it is tedious to work with it. Hence, a process where just enough water vapour is introduced which chemically combines to a safer zone and it is commercially called as hydrated lime and the process is called as slaking. In this study, hydrated lime purchased from dindigul is used. To satisfy the codal provisions of calcium oxide, reactivity test is performed for the sample and the available CaO in the sample is 63.2 % which is satisfactory [13].

Gypsum:

Gypsum is a by-product of phosphoric acid fertilizer industry. Natural gypsum is also available and it is used as fertilizer. The chemical formula for gypsum is $CaSO_4.2H_2O$ and it is used as boards in construction industry. In cement manufacturing, gypsum is used as a retarder. It is considered one of the main constituent in plaster, wall board and usually gypsum is introduced around 5 % in fly ash bricks. In this study, gypsum is purchased from Thoothukudi.

M-sand:

The demand of natural river sand is increasing day by day. Due to the depletion of river sand environment problems arises. Many researches were done using crushed rock as fine aggregate and the properties were discussed. Manufactured sand is found to be an alternative for fine aggregate which is produced by blasting, crushing, screening and further processing [8]. In the process of crushing rocks including M-sand, P sand (plastering sand) is also collected. Difference between the M-sand and P-sand is the particle size. Hence, P-sand is used for all types of plastering, roofing and tiling purposes. The source rocks for M-sand and P-sand is black granite rocks. In this study, M-sand is used and it is purchased from Thirumayam.

Parameter design methodology

There are many methods to design an experiment and optimize the process. Some of the methods included are full factorial method, response surface methodology and taguchi design. Full factorial design can be used for two or more factors with possible discrete levels. The experiment runs will have all possible combinations. If there are k factors each at n levels then the number of trials is n^k. It has many experiments and become tedious to carry out the trials [14]. Taguchi is an optimization technique developed by Genichi Taguchi. This method involves orthogonal arrays to organize the parameters which affect the factors and levels to be varied. The factors and the levels are chosen in such a way that it should not be confounded by other effects. In this, signal to noise ratio is considered which is used in evaluating the quality of product [15]. It can be classified as smaller is better, larger is better and nominal is better.

Design of Experiments

In this study, control factors and levels are chosen based on the preliminary trials and it is shown in table 2. It has 4 control factors and 3 levels. In case of full factorial method, it runs on all possible combinations and the number of trials is 81(n^k). In case of Taguchi method, involves the orthogonal arrays to design the experiments. Using this design, large number of experiments involving the variables decreases to limited trials which are also valid for the overall experiment. In this study, the control factors and levels are chosen based on the preliminary trials and it is shown in table 2. An $L_9\,(3^4)$ standard orthogonal array is employed. The number of trials can be determined by the formula $N = 1 + K\,(L - 1)$, where K denotes number of factors and L denotes number of levels. For this experiment, $N = 1 + 4(3 - 1) = 9$ which is the number of trials for this design. Using taguchi design, the number of trials can be decreased which helps the process easier. The standard orthogonal array $L_9(3^4)$ is shown in table 3 and the layout design is shown in table 4.

Table 2: Control factors and levels

Factors	Factors Designation	Level 1	Level 2	Level 3
Water / binder ratio	A	0.3	0.325	0.35
Fly ash (%)	B	30	40	50
Lime (%)	C	10	15	20
Gypsum (%)	D	3	5	8

Table 3: $L_9(3^4)$ Standard Orthogonal array

Exp no.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 4: Layout of Experimental design

Exp. no.	Factor A W / B ratio	Factor B Fly ash (%)	Factor C Lime (%)	Factor D Gypsum (%)
1	0.325	30	10	3
2	0.325	40	15	5
3	0.325	50	20	8
4	0.3	30	15	8
5	0.3	40	20	3
6	0.3	50	10	5
7	0.35	30	20	5
8	0.35	40	10	8
9	0.35	50	15	3

METHODOLOGY

Concluding the experimental design, the bricks were casted by machine as per the design trails and the methodology is shown in the flow chart.

Fig 1: Fly ash bricks casting machine

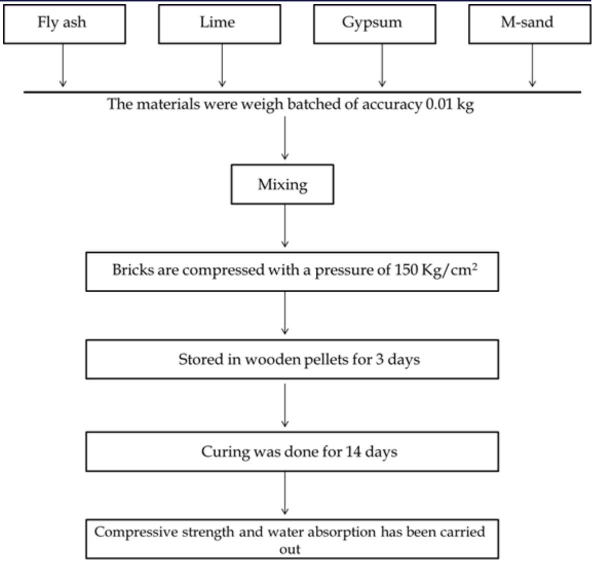

Fig 2: Compressing fly ash bricks with a pressure of 150 Kg/cm^2

From the flow chart mentioned, the materials are weigh batched and the quality is assured and it is mixed in the pan mixer of fly ash brick making machine. The materials are mixed uniformly and it passed to the hydraulic compressing where the pressure can be applied in the range of 150 - 250 Kg/cm^2. The bricks are casted and it is transported manually for wooden pellets and stored in a covered place for 3 days minimum and taken to the yard for water curing for 14 days and it is tested for compressive strength and water absorption.

Analysis and Results

The bricks were tested using compressive testing machine of capacity 2000 KN. Each experiment has three specimens and the corresponding responses are shown in table 5. In taguchi method, the main effects plot is determined by signal to noise ratio(S/N ratio). Generally, it is classified as three types namely smaller is better, nominal is better and larger is better. It is chosen based on the maximization and minimization properties of the response.

Table 5: Results for compressive strength and signal to noise ratio

Experiment No.	Compressive strength of bricks (N/mm2)				S/N Ratio
	Reading 1	Reading 2	Reading 3	Mean	
1	8.772	8.187	9.942	8.967	19.053
2	12.865	9.942	11.696	11.501	21.215
3	20.468	19.298	21.637	20.468	26.221
4	11.696	8.772	10.526	10.331	20.283
5	8.187	9.357	7.018	8.187	18.263
6	18.713	15.789	18.129	17.544	24.885
7	21.637	20.468	22.807	21.637	26.704
8	13.450	9.942	11.696	11.696	21.646
9	22.807	22.222	22.807	22.612	27.089

The highest signal to noise ratio is chosen for the maximization for compressive strength. From The main effect plot for means shown in fig 3, the optimal levels of parameters are,

Water/Binder ratio – 0.35, Fly ash – 50 %, Lime – 20 %, Gypsum – 5%

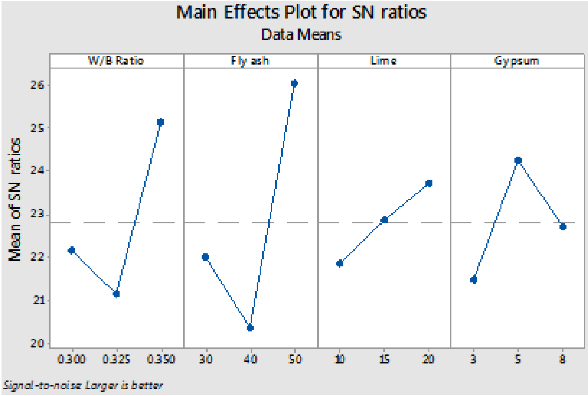

Fig 3: Main effects plot for signal to noise ratios

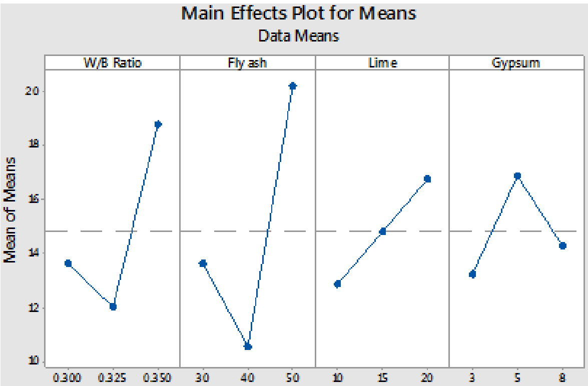

Fig 4: Main effects plot for means

Analysis of Variance (ANOVA) is performed and the regression equation for the response is,

Mean = 386 – 1147A + 2.5B – 40.4C +2.57D – 8.8A*B + 113.2A*C + 0.0939B*C

Where, A – Water Binder ratio, B – Fly ash, C – Lime, D – Gypsum

With this equation, the optimal trial is predicted and it is observed that the mean value is **46.6994** and the SE fit is **10.8328** and the 95 %confidence interval is beyond the limits. Hence, confidence interval is decreased to 85 % confidence interval and the limits obtained are **(1.57735, 91.8213).** Also the experiment trial has been carried out and the mean compressive strength if found out to be **28.741 N/mm^2.**

Water absorption

The water absorption for the fly ash bricks is determined for every experiment of two specimens and the result is tabulated in the table 7.

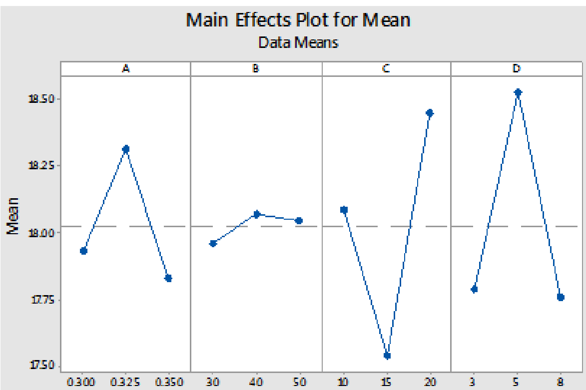

Fig 5: Main effects plot for Means

Table 6: Results for Signal to noise ratio

Experiment No.	Water Absorption (%)		
	Reading 1	Reading 2	Mean
1	16.69	18.69	17.69
2	18.44	17.56	18.00
3	17.96	18.26	18.11
4	17.00	18.00	17.50
5	18.90	18.20	18.55
6	18.50	19.30	18.90
7	18.73	18.65	18.69
8	17.33	18.00	17.67
9	17.10	17.16	17.13

The optimal proportion for the water absorption is,

Water/Binder ratio – 0.325, Fly ash – 40 %, Lime – 20 %, Gypsum – 5%

Water absorption for every trail is satisfactory as per the codal provisions.

CONCLUSION

From these experimental observations it is studied that fly ash bricks are eco-friendly and economical one when compared to the conventional clay brick. It negotiates the manpower work and also the high quality control. Since the manufacturing is a mechanical process quality control is assured. In earthquake free areas, fly ash bricks can be used as a load bearing one up to three storey load bearing buildings. The cost is compared to the normal conventional brick of class designation 20Mpa. Cost of normal first class brick is 12 rupees per brick while the fly ash brick excluding transporting charges is around 2.5 rupees.

From the literature studies taguchi method is used as an optimization for fly ash bricks where the interaction study is not considered. The maximum compressive strength from the experimental trials is **22.612 Mpa** which is much better than the conventional clay bricks. With the main effect plot, the optimal mix is observed and the predicted fit value is 46.6994Mpa where the mix proportion is carried out experimentally and the result obtained is 28.741Mpa. The predicted value deviates from the experimental value which shows the interactions between the chosen input parameters. For the accurate prediction of proportioning fly ash bricks it is better to use Response Surface Methodology (RSM) rather than taguchi method by considering the interaction studies.

Water absorption for every experimental trial is satisfactory hence Analysis of Variance is not considered.

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