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A REVIEW: TAGUCHI EXPERIMENT DESIGN FOR INVESTIGATION OF PROPERTIES OF CONCRETE

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ABSTRACT

Taguchi method is a process optimization technique to investigate the effects of various parameters simultaneously by conducting minimum number of experiments. This approach helps to select the best combination of control parameters so that the product or process is most robust with respect to noise factors. The Taguchi method is a widely used Design of Experiment (DOE), different from other conventional ones and it employs various orthogonal arrays to systematically vary and test different levels of each of the control factors. The parameters affecting the product may be controllable and uncontrollable, so by eliminating the uncontrollable parameters the cost and performance of the experiment could be increased. This review study on Taguchi method explained the optimum control factors that can be chosen for experimental studies in concrete by limiting the time and resources.

KEYWORDS: Taguchi Method, Robust Design, Orthogonal Array, Signal to Noise Ratio

INTRODUCTION

To determine the effects of various factors which effect the results of experiments, different methods and approaches were used. The Taguchi methodhelps to reduce the variations in process through robust design of experiments. The main objective of the method is to enhance the product quality keeping at low cost to the manufacturer. Therefore, poor quality in a process affects not only the manufacturer but also society. This is a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning.

The experimental design proposed by Taguchi considers various orthogonal arrays to organize the parameters affecting the process and decides the levels at which they should be varied. By determining the factors which mostly affect the product quality with a minimum amount of experimentation, it allows for the collection of the necessary datathus saving time and resources. By analysing the variances on the collected data from the Taguchi design of experiments, a new set of parameter values can be selected to optimize the performance characteristic.

TAGUCHI METHOD

Taguchi method is a statistical method developed by Genichi Taguchi during the 1950s as an optimization process technique. It is used for optimizing the process of experimentation in an effort to improve robust and design productivity

and enhance product quality. The idea behind robust design is to improve the quality of a product by minimizing the effects of variation without eliminating the causes (since they are too difficult or too expensive to control). Taguchi's approach to parameter design provides the design engineer with a systematic and efficient method for determining near optimum design parameters for performance and cost.

In parameter design, there are two types of factors that affect a product's functional Characteristic, control factors and noise factors. Control factors are those factors which caneasily be controlled. Noise factors are factors that are difficult or impossible or too expensive tocontrol. These are primarily response for causing a product's performance to deviate from its target value. Hence, parameter design seeks to identify settings of the control factors which make the product insensitive to variations in the noise factors, therefore make the product more robust, without actually eliminating the causes of variation.

The Taguchi method is a very efficient optimization tool that uses orthogonal arrays (OA). These are highly mixed experimental designs in which a maximum amount of main effects are tested with a minimum number of experiments. Using an OA to design the experiment helps the designer to study the influence of multiple controllable factors on the average of quality characteristics and the variations in a fast and economic way. OA's allow screening out few important main effects from the many less important ones. Also it allows us to estimate interaction effects if any and determine their significance. Commonly used OAs include the L_4, L_9, L_{12}, L_{16}, L_{18}, and L_{28}.The columns in the OA indicate the factor and its corresponding levels, and each row in the OA constitutes an experimental run which is performed at the given factor settings. Selecting the number of levels and quantities properly constitutes the bulk of the effort in planning robust design experiments. Table 1,2&3 shows some orthogonal arrays. Each orthogonal array is uniquely defined by a code and it allows selection of appropriate arrays depending on the number of parameters and their stages.

In the code $L_m(m^k)$

- **n:** number of lines
- **m:** number of parameter levels
- **k:** number of parameters

Table 1: Representation of L_4 (2^3) Array

RUN	FACTORS		
	A	B	C
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

Table 2: Representation of L_8 (2^7) Array

RUN	FACTORS						
	A	B	C	D	E	F	G
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1

7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

Table 3: Representation of $L_9(3^4)$ Array

RUN	FACTORS			
	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

Taguchi uses two experimental designs for its experimental procedure, called inner and outer arrays. All control factors are placed in the inner array, while all noise factors are considered in the outer array. Each factor level combination of control factors from the inner array is tested against various combinations of the noise factors in the outer array. The behaviour of each factor level combination of control factors can be tested under the influence of noise factors. It should be noted that a variation of the control factors due to repeated measures, such as adjustment errors, is mixed in with the noise factors. This means that the corresponding uncertainty can be regarded as an inner noise factor and that the system is designed to be robust against these noise factors. The combination of the "inner array" and "outer array" constitutes what is called the "product array". The product array is used to systematically test various combinations of the control factor settings over all combinations of noise factors after which the mean response and standard deviation may be approximated for each run. The preferred parameter settings are then determined through analysis of the "signal-to-noise" ratio.

Signal-To-Noise Ratio

Taguchi method uses the S/N ratio (signal-to-noise), which is a performance characteristic, instead of the average value to interpret the trial result data into a value for the evaluation characteristics in the optimum setting analysis. This ratio expresses the scatter around a target value.

There are three standard types of SN ratios depending on the desired performance response

- **Smaller the Better (For Making the System Response as Small as Possible)**

  The S/N can be calculated as given in equation 1

  $$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

- **Nominal the Best (For Reducing Variability around a Target). The S/N can be Calculated as given in Equation 2**

  $$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} (y_i - y_0)^2\right)$$

- **Larger the Better (For Making the System Response as Large as Possible). The S/N can be Calculated as Given in Equation 3**

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$$

Where Yi is a performance value of the i^{th} trial and n is the number of repetitions for anexperimental combination.

LITERATURE REVIEW

Achievement in experiments based on properly design product. In some cases, it is necessary to study on a lot of combinations of experiment. This is difficult to apply it for user and need more time. The Taguchi method of experiments is a statistical tool based on the systematic approach of conducting minimal number of experiments using orthogonal arrays. Traditionally, this method has been used to predict the significant contribution of each design variables and the optimum combination of design variables by conducting a real time experiment. Atill and Unver reported that the design of experiments using Taguchi method is more efficient compared to statistical methods. By choosing proper level combinations of various independent variables, the number of experiments is reduced considerably. At the same time, there is no loss of any information due to reduction of number of experiments. Taguchi's target was minimising the variation around the target and improve the quality. Using and learning this technic for engineers, scientists and researchers, time needing in researches is become less. [1]

Ozbayet. alInvestigated mix proportions of high strength self-compacting concrete by using Taguchi method. The mixtures are designed in a L_{18} orthogonal array with six factors such as water cementitious material (W/C) ratio, water content (W), fine aggregate to total aggregate percent, fly ash content, air entraining agent content, and superplasticizer content.They reported that Taguchi method is a promising approach for optimizing mix proportions of high strength self-compacting concrete to meet several fresh and hardened concrete properties. Taguchi method can simplify the test protocol required to optimize mix proportion of high strength self-compacting concrete by reducing the number of trial batches. [2]

Shariq et al evaluated the various mix proportions using full factorial design. Empirical relationships for compressive strength were derived as function of mix ingredients. Design of concrete mixes is influenced by various factors, which depends upon the sources of materials and their properties, method of preparation, placement, compaction and curing of concrete, and the requirement of a construction job. For an aggregate from a particular source having a specific grading the optimum design of a concrete mix involve selection of proportions of ingredients that yield concrete of the desired strength, workability, and durability at minimum cost. The most important factors which influence are the water cement ratio (W/C), aggregate-cement ratio (TA/C) and the coarse aggregate to total aggregate ratio (CA/TA). Since these factors are interdependent hence study for various combinations is necessary. They created a statistical model for concrete strength as a function of w/c ratio, CA/TA ratio and TA/C ratio in terms of interpolating polynomial has been established. Good agreement is found between the computed and experimental values. [3]

Ramaswamy used Taguchi Technique to conduct performance based optimization studies on the design of fireworks industrial structures. The existing construction guidelines are inadequate to resist against the failure or collapse of brick masonry structures in the event of an accidental explosion. Therefore an attempt is made to identify the optimum structure or configuration which can perform satisfactorily against such accidental explosions. Taguchi based optimization technique using Minitab software was used to arrive at the ideal model structure for fireworks industrial building that shows satisfactory performance against the accidental explosive loading. From the main effects plot, it was observed that the slopes of line is reducing in the order of wall thickness, roof design and shape of the building. Mean graph illustrates

that the brick masonry model having 230 mm thick wall of square shape and tapered roof design can be considered as the best. [4]

Nuruddin and Bayuaji investigated on the application of Taguchi's approach in the optimization of proportion for microwave incinerated rice husk ash foamed concrete. The mixtures are designed in L16 orthogonal array with five factors. They are microwave incinerated rice husk ash (mirha) contents, water cementitious ratio (w/c), sand cement ratio (s/c), superplasticizer (sp) content, foam content. The best possible levels of mix proportions are determined for maximization through compressive strength, splitting tensile strength, UPV. Dry density, porosity, and water absorption can be really minimized by the proposed optimum mixture proportions. [5]

Turkmen et al carried out a study on the investigation of some physical properties of concrete produced from mineral admixtures using Taguchi approach. They found out that Taguchi method can successfully be applied to physical properties of high strength concrete to save energy, time, and material in experimental study. The factors considered in this investigation were mineral admixture, water-to-binder ratio, curing regime and curing time. The results shows that the durable mixtures to be the one prepared with 10% silica fume and 5% blast furnace slag. Due to the existence of too many material content of self-compacting concrete, a number of experiments were conducted to opt a suitable mixture satisfying the needed requirements of self-compacting concrete. [6]

Hadiwidodo and Bin Mohd conducted studies for the investigation of Freshened Properties of Self-Compacting Concrete using Taguchi experimental design. Six control factors, namely, contents of coarse aggregate, sand, cement, silica fume, water and super plasticizer were used. The result of this study showed that Taguchi method is a promising approach for optimizing mix proportions of SCC to meet several freshened concrete properties. [7]

Tan et al made an investigation using Taguchi approach for optimization of the bleeding on cement-based grouts. The effect of the bentonite (B), fly ash (FA) and silica fume (SF) on the bleeding of cement-based grouts were considered. L16 orthogonal array (OA) with three factors and four levels were used. The results showed that Silica fume is the most effective material for the bleeding. The bleeding decreased with the increase in SF and B ratio, while there was no noticeable difference with the increase of FA. Also the optimum conditions for minimum bleeding were found out.[8]

Tanyildizi and Sahin carried out a study for optimization of concrete strengthened with polymer after high temperature using Taguchi method. They investigated statistically the importance of experimental parameters on the compressive strength and ultrasonic pulse velocity of the concrete strengthened with polymer after exposure to high temperature. The main parameters of experiments were selected as the polymerization type, the percentage of silica fume, and heating degree. The significance levels of the experimental parameters, which indicate how the factors affect the compressive strength and ultrasonic pulse velocity, were determined by using variance (Anova) method. The ANOVA results showed that the silica fume percentage was the most significant effect onthe compressive strength and ultrasonic pulse velocity [9]

CONCLUSIONS

Taguchi method is the most feasible method to reduce the number of experiments. It helps to identify the influence of factors in a particular experiment. In regression analysis, analysis of variance table helps to identify the contribution percentage of factors in a particular experiment. While using Taguchi method in an experiment, can predict the response characteristics for selected factors. The result optimization is easily possible with the help of Taguchi method.

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