

Developing Analytical Model for Composite Circular Steel Columns (CCST) Subjected to Axial Compression using ANNOVA-(TAGUCHI'S APPROACH)

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ABSTRACT: CCST's with recycled aggregate mixed different grades of concrete is modelled using Taguchi's approach and results are verified with the help of a statistical tool-Analysis of variance (ANNOVA) using MINITAB-V16 to reduce the error variance and to identify the dominant control factor i.e. proper combination of diameter, thickness and length of composite tubes for three different levels. Grades of concrete are taken as levels and length, diameter and thickness of the tube as factors. Hence Taguchi's L9 (Latin square) orthogonal array is considered. Regression Models are developed with minimum number of the experiments based on the Taguchi's method to predict axial load carrying capacity of composite tubes. Model developed with MINITAB-v17 are verified with experimental value.

KEYWORDS: Composite Circular Steel Columns (CCST's), ANNOVA, Taguchi's Approach, Regression Models.

I. INTRODUCTION

In the last decade due to the large number of earthquakes, many buildings have been demolished leading to the formation of large wastes which is further destroyed by burying into the earth. In order to use the construction waste effectively, save our living space and preserve our environment, and to suit the need of low carbon economy, a lot of research have been carried out to investigate the strength and behaviour of the recycled aggregate concrete (RAC) and the composite structures which is made of or be filled with recycled concrete.

A large economic drop is faced by the area where these disasters occurs. To restore the same, it is required to construct the buildings and other structures very economically. The use of such huge debris can be economically used for the construction. To reuse these wastes, the strength is required to be designed. The Taguchi's approach can be effectively used to get the strength of the composite steel tube with infill as recycled materials.

Further the axial load taking capacity of these tubes can be predicted by the modelled equations. Different approaches of the regressions are employed to get the regression equations and the error in the same is predicted. The difference in the values of these modelled equations are compared and the suitable method is suggested based on the results.

In this research, circular steel tubes of three different diameter each with different Thickness and three different lengths are selected for testing.

Taguchi's L9 (Latin squares) -Orthogonal array is used in order to save time and cost of experimentation and also to determine the effect of each parameter on the axial loading.

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II. RELATED WORK

In order to save time and material cost involved in experimentation, lesser number of experiments are desired. Therefore Taguchi's method is adopted. Experiments are carried out according to combination levels indicated by L9 orthogonal array (Table I) for three grades of in filled concrete for steel tubes. An orthogonal array helps in determining the number of trails that are necessary, and factor levels for each parameter. A general L9 orthogonal array consists of combination of experiments with three factors each at three levels.

A	B	C	D
1	1	1	1
1	2	2	2
1	3	3	3
2	1	2	3
2	2	3	1
2	3	1	2
3	1	3	2
3	2	1	3
3	3	2	1

Table (1) Taguchi's L9 Design with 3-Levels and 4-Factors

III. SPECIMEN DETAILS

The Steel tubes are cut to different lengths of as per Taguchi's L9 combination considering respective l/d ratio are tested for ultimate axial load and axial shortening under an Cyclic Loading Equipment as per Taguchi level-3 design (Table-1) with 4- factors tubes are placed upright for compression loading with proper end conditions after curing the in filled tubes for 28days.

The tests are performed on circular steel tubes of nine different combinations of dimensions as per the Taguchi's orthogonal array as shown in the figure (Table-1).

In this investigation, Circular Steel tubes with three different Diameters (42.4mm,48.3mm,60.3mm) each with different Thickness(2.9mm,3.2mm,4.0mm), Lengths (300mm,500mm,600mm), l/d ratio (5-15) are selected for testing . Suitable Factors and levels are considered for each type of infill as per Taguchi's Method of Design of Experiments (DOE).

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LENGTH(mm)	DIAMETER(mm)	THICKNESS(mm)	%(RCA)
300	42.4	2.9	0
300	48.3	3.2	50
300	60.3	4	100
500	42.4	3.2	100
500	48.3	4	0
500	60.3	2.9	50
600	42.4	4	50
600	48.3	2.9	100
600	60.3	3.2	0

Table (2) Experimental values of Ultimate load capacity and Axial shortening

IV. VALUES OF EXPERIMENTATION

The different values of axial compressive strength and the axial shortening is obtained for the given specimen (Table 2). The following values table (3) of the experiments were obtained in an experiment under the guidance of Dr. N.S. Kumar.

Design of experiment is conducted on the following combinations. The benefit of using the Taguchi's L9 array is to reduce the number of experimentations. This L9 array consist of three values of diameters, lengths, and thicknesses.

LENGTH(mm)	DIAMETER(mm)	THICKNESS(mm)	%(RCA)	Pu(20)	Pu(40)	Pu(60)	AS(20)	AS(40)	AS(60)
300	42.4	2.9	0	199	206	225	100.32	101.34	98.41
300	48.3	3.2	50	262	305	307	97.02	246.65	102.61
300	60.3	4	100	412	436	445	106.54	88	107.18
500	42.4	3.2	100	159	169	188	100.57	95.87	98.03
500	48.3	4	0	210	220	191	100.85	94.1	95.87
500	60.3	2.9	50	249	314	302	117.97	98.16	99.05
600	42.4	4	50	164	164	178	92.83	94.22	96.54
600	48.3	2.9	100	189	185	195	94.99	96.38	95.11
600	60.3	3.2	0	383	443	452	102.1	99.05	99.94

Table (3) Experimental values of Ultimate load capacity and Axial shortening

Pu(20) = Axial compressive strength of M20 concrete
 Pu(40) = Axial compressive strength of M40 concrete
 Pu(60) = Axial compressive strength of M60 concrete
 AS(20) = Axial shortening of M20 concrete
 AS(40) = Axial shortening of M40 concrete
 AS(60) = Axial shortening of M60 concrete

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V. DESIGN OF EXPERIMENT USING TAGUCHI'S APPROACH

The following equations are modelled using MINITAB-v16 and the values are obtained for the three different regression analysis. These equations are very helpful to determine the ultimate axial strength and axial shortening, which are further used to get the same of different combination of composite tubes. These equations are used for the same L9 array combination and the error in the values can be determined. The regression is performed in three different ways and they are modelled below.

REGRESSION EQUATIONS

$$\begin{aligned}Pu(20) &= -270 - 0.191 \text{ LENGTH} + 9.86 \text{ DIAMETER} + 34.3 \text{ THICKNESS} - 0.107 \%(\text{RCA}) \\Pu(40) &= -307 - 0.206 \text{ LENGTH} + 12.4 \text{ DIAMETER} + 19.3 \text{ THICKNESS} - 0.263 \%(\text{RCA}) \\Pu(60) &= -243 - 0.215 \text{ LENGTH} + 11.7 \text{ DIAMETER} + 10.7 \text{ THICKNESS} - 0.133 \%(\text{RCA}) \\AS(20) &= 83.3 - 0.0096 \text{ LENGTH} + 0.660 \text{ DIAMETER} - 3.10 \text{ THICKNESS} - 0.0039 \%(\text{RCA}) \\AS(40) &= 296 - 0.175 \text{ LENGTH} - 0.72 \text{ DIAMETER} - 18.9 \text{ THICKNESS} - 0.047 \%(\text{RCA}) \\AS(60) &= 88.7 - 0.0195 \text{ LENGTH} + 0.261 \text{ DIAMETER} + 1.60 \text{ THICKNESS} + 0.0203 \%(\text{RCA})\end{aligned}$$

ORTHOGONAL REGRESSION

$$\begin{aligned}Pu(20) &= -679.0 + 60.86 \text{ D/T} \\Pu(40) &= -630.3 + 59.23 \text{ D/T} \\Pu(60) &= -640.7 + 60.21 \text{ D/T} \\AS(20) &= 68.22 + 2.184 \text{ D/T} \\AS(40) &= -18009 + 1190 \text{ D/T} \\AS(60) &= 94.59 + 0.302 \text{ D/T}\end{aligned}$$

GENERAL REGRESSION

$$\begin{aligned}Pu(20) &= -269.512 - 0.19119 \text{ LENGTH} + 9.85531 \text{ DIAMETER} + 34.2955 \text{ THICKNESS} - 0.106667 \%(\text{RCA}) \\Pu(40) &= -306.712 - 0.205714 \text{ LENGTH} + 12.3603 \text{ DIAMETER} + 19.3299 \text{ THICKNESS} - 0.263333 \%(\text{RCA}) \\Pu(60) &= -243.094 - 0.215238 \text{ LENGTH} + 11.723 \text{ DIAMETER} + 10.7045 \text{ THICKNESS} - 0.133333 \%(\text{RCA}) \\AS(20) &= 83.3383 - 0.00960238 \text{ LENGTH} + 0.660134 \text{ DIAMETER} - 3.09605 \text{ THICKNESS} - 0.0039 \%(\text{RCA}) \\AS(40) &= 296.24 - 0.174576 \text{ LENGTH} - 0.717618 \text{ DIAMETER} - 18.9019 \text{ THICKNESS} - 0.0474667 \%(\text{RCA}) \\AS(60) &= 88.7252 - 0.01945 \text{ LENGTH} + 0.260847 \text{ DIAMETER} + 1.60361 \text{ THICKNESS} + 0.0203333 \%(\text{RCA})\end{aligned}$$

VI. TABULATION OF RESULTS

The different values of the length, diameter and thickness is substituted in place of the different regression equations And the results are tabulated for each grade of the concrete used. The result here consist of the three types of the regressions. The values obtained from the regression and experimental values can be easily compared and the best regression method could be suggested based upon the values obtained.

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Pu60	Pu60(REGRESSION)	Pu60(GENERAL REGRESSION)	Pu60(ORTHOGONAL)
225	239.11	220.43285	239.6117

Pu20	PU20(REGRESSION)	Pu20(GENERALREGRESSION)	Pu20(ORTHOOGONAL)
199	190.234	190.453094	210.8152
262	253.348	253.554723	239.6056
412	393.758	393.921493	238.4645
159	151.624	151.837044	127.395
210	247.938	248.086473	55.8845
249	323.178	323.291793	586.4683
164	165.314	165.487794	--
189	180.408	180.575723	334.6338
383	319.718	319.794793	467.8306

Pu40	Pu40(REGRESSION)	Pu40(GENERAL REGRESSION)	Pu40(ORTHOGONAL)
206	212.93	211.70723	263.7028
305	278.73	277.26547	262.5923
436	429.82	427.88649	154.4975
169	151.22	150.0304	84.90225
220	266.12	264.75309	601.2755
314	380.54	378.6473	--
164	159.21	158.08942	356.1859
185	197.99	196.5858	485.8153
443	378.88	377.04137	--
307	304.7	286.14325	268.0947
445	447.01	428.7162	266.9658
188	199.02	167.2633	157.0825
191	289.91	258.3259	86.33575
302	411.89	380.5603	611.2528
178	199.23	160.96975	--
195	249.84	211.69385	362.1079
452	406.75	368.9145	493.8822

VII. MAIN EFFECT PLOTS AND RESULTS

After performing the experiment as per the Taguchi's method, main effect plots are obtained for axial shortening and axial compressive strength. A minimum effect is a direct effect of parameters on the response and dependable variables. From the graph and the results obtained by MINITAB-v16 it can be concluded that the **DIAMETER** is the main parameter for the maximum ultimate load. It is ranked 1 among the other different 3 parameters

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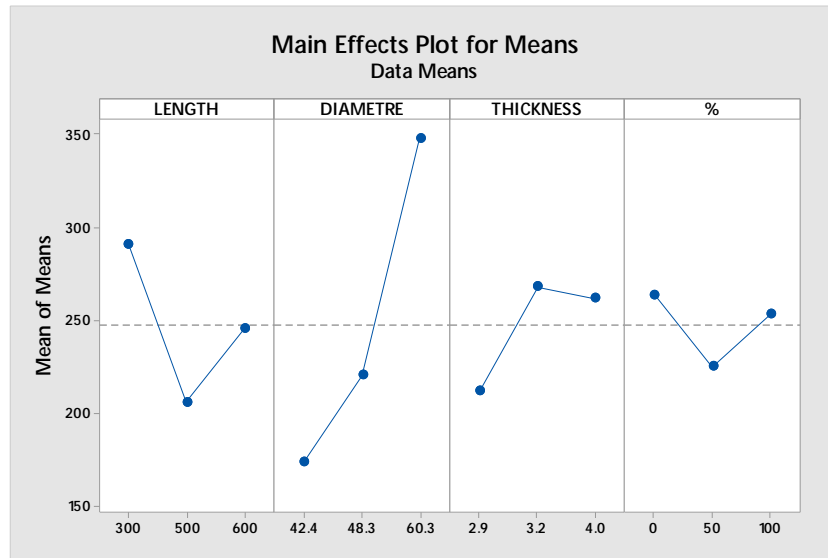
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Response Table for Means

Level	LENGTH	DIAMETER	THICKNESS	%
1	291.0	174.0	212.3	264.0
2	206.0	220.3	268.0	225.0
3	245.3	348.0	262.0	253.3
Delta	85.0	174.0	55.7	39.0
Rank	2	1	3	4



VIII. SIGNAL TO NOISE RATIO GRAPHS

S/N ratio is used as measurable value instead of standard deviation due to the fact that, as the mean decreases, the standard deviation also decreases and vice versa. In other words, the standard deviation cannot be minimized first and the mean brought to the target. In practice, the target mean value may change during the process development. Two of the applications in which the concept of S/N ratio is useful are the improvement of quality through variability reduction and the improvement of measurement.

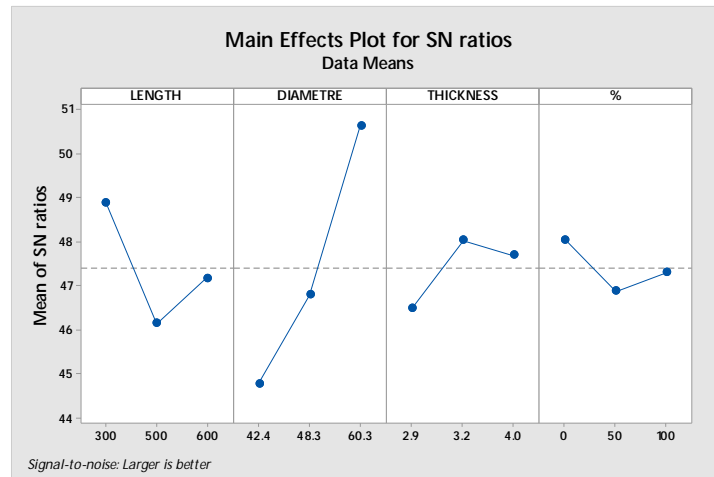
Taguchi method stresses the importance of studying the response variation using the signal – to – noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The diameter increasing rate was considered as the quality characteristic with the concept of "the larger-the-better".

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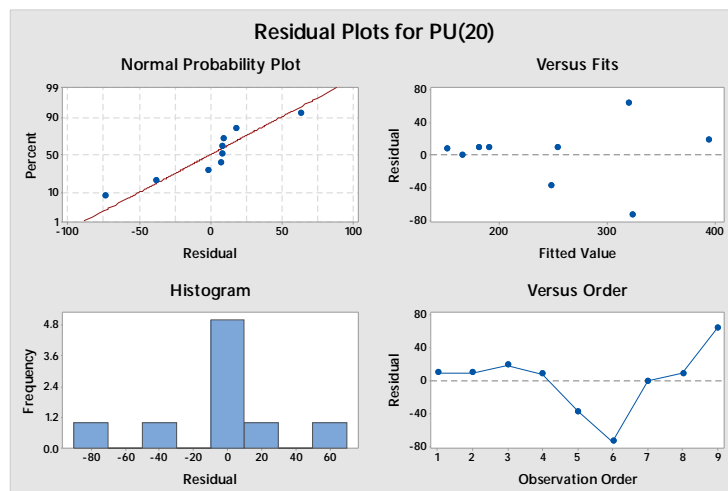
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IX. RESIDUAL PLOTS

After performing the experiments as per Taguchi's experimental design the residual plots are obtained for the ultimate axial load for steel tubes. **Residual plot** is a graph that shows the residuals on the vertical axis and the independent variable on the horizontal axis. If the points in a residual plot are randomly dispersed around the horizontal axis, a linear regression model is appropriate for the data; otherwise, a non-linear model is more appropriate.



X. INTERACTION PLOT

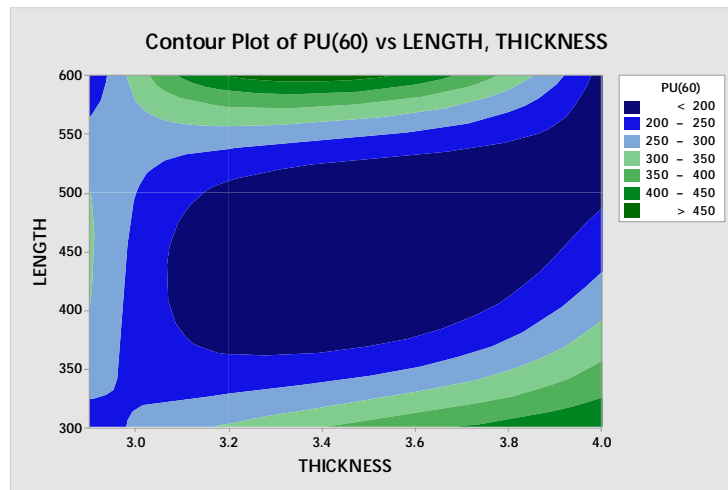
Contour plots are for the ultimate load and axial shortening for all the three levels of the steel tubes. It is plotted for thickness, axial load and axial shortening and length is also plotted. The graph drawn in the below figure is represents ultimate axial load with M60 concrete. The plots explain that for thickness range of 3.2 -4.0 mm but is varying with different combination in range Refer contour plots. We also observe how distribution of load carrying capacity of Column with changes in L/D ratio.

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XI. CONCLUSION

- Among the three different types of regressions done, the simple regression seems to be more efficient in getting the economic axial compressive strength.
- The orthogonal regression is less efficient because the factors affecting the ultimate strength taken by the method is only two. Therefore orthogonal regression is much suitable in the experiment where the factors are two or maximum three.
- From the regression analysis, the compressive strength and axial shortening of the any given section can be easily determined.
- It is now easy to obtain the strength of the recyclable concrete without performing the actual experiment.
- A large amount of economy can be saved with about 60-70% efficiency

XII. ACKNOWLEDGEMENT

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