Experimental Investigation on Seismic Resistance of Recycled Concrete in Filled Steel Columns - Taguchi's Approach

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SUMMARY:
Experimental investigation on Composite Circular Columns in filled with different grades of recycled concrete is tested for Seismic Resistance. Recycled concrete is used as infill in this study as in post seismic hazard situation there is huge debris available due to the destruction and it becomes an easily accessible material for post disaster reconstruction. As it is an eco-friendly material it would get Carbon Credits and LEED rating. Steel tubes are tested for different combination of Length, Thickness & Diameter with the help of Taguchi's L9 (Latin squares) -Orthogonal array in order to save time and cost of experimentation and also to determines the effect of each parameter. Results were obtained for the L9 orthogonal combination from experimentation. The obtained results were analysed with the help of Signal/Noise (S/N) Ratio, Main Effects Plot & Analysis of variance (ANOVA) using Mini Tab V16. Regression equations are developed for all three grades of infill's separately. Artificial Neural Networks are developed and trained to predict the ultimate load carrying capacity and axial shortening of columns. Feed Forward Network comprises 4 input nodes, 2 output nodes, and 3 hidden layer nodes using sigmoid layers. Hence, this is a complex study of behaviour of Recycled Concrete as infill in steel columns using Taguchi's approach. This Study confirms advantage of Recycled Concrete as infill in composite columns to resist seismic loadings.

Keywords: Composite, Recycled Aggregates, Taguchi, Main effects, S/N Ratios.

1. INTRODUCTION

With the development of the global economy, the construction industry is growing rapidly. Large amounts of waste concrete produced such as by road uploading, demolition of existing structures. Especially, during the natural disasters such as the earthquake broke out in Sichuan on 12th May, 2008, Bhuj earthquake 2001, Sikkim earthquake on 18th September 2011 in India, many concrete structures have collapsed and damaged which are to be reconstructed. Therefore, there is huge number of construction and demolition waste has been produced over the last decade in India or the other developing countries like China and Brazil etc.

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 behavior of the recycled aggregate concrete (RAC) and the composite structures which made of or be filled with recycled concrete. Recycled aggregate concrete filled steel tube (RACT) columns have been increasingly attracted worldwide researchers and have been widely used in many structures due to their high strength, high ductility, high stiffness, high seismic resistance and full usage of the construction materials.

In order to reveal the performance of steel recycled composite columns, 81 specimens will be designed for axial compression loading experiment. The two types of concrete that will be considered are Natural & Recycled Concrete for infill in steel tubes.

Based on these factors failure patter and influence of recycled coarse aggregate replacement and slenderness ratio to axial compression load capacity are analyzed. For axial compression load of steel recycled composite columns will be developed.

Table 1. Nomenclature

Nomenclature	
Pu(20)	Ultimate axial load of steel tubes in filled with M20
Pu(40)	Ultimate axial load of steel tubes in filled with M40
Pu(60)	Ultimate axial load of steel tubes in filled with M60
Ppu(20)	Predicted Ultimate axial load of steel tubes with M20
Ppu(40)	Predicted Ultimate axial load of steel tubes with M40
Ppu(60)	Predicted Ultimate axial load of steel tubes with M60
As(20)	Axial shortening of steel tubes in filled with M20
As(40)	Axial shortening of steel tubes in filled with M40
As(60)	Axial shortening of steel tubes in filled with M60
Asp(20)	Predicted Axial shortening of steel tubes in filled with M20
Asp(40)	Predicted Axial shortening of steel tubes in filled with M40
Asp(60)	Predicted Axial shortening of steel tubes in filled with M60

2. EXPERIMENTAL PROGRAM

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).

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 with empty and in filled tubes with Normal Aggregate Concrete (NAC) & Recycled Aggregate Concrete (RAC) (M20, M40 & M60) as per Taguchi level-3 design (Table-2) with 4- factors tubes are placed upright for compression loading with proper end conditions after curing the in filled tubes for 28 days.

Table 2. Taguchi's L9 Design with 3-Levels and 4-Factors

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

Figure 1. Columns being tested under Cyclic Loading Equipment

Figure 2. Steel Composite Columns under Curing

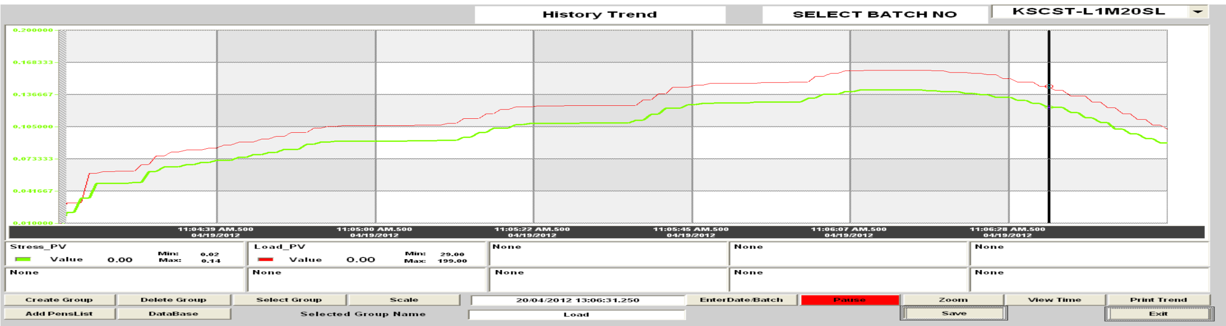

Figure 3. History trend of Sustained Loading of specimen

3. ANALYSIS OF RESULTS

3.1. DOE Approach

In order to save time and material cost involved in experimentation, lesser number of experiment are desired. Therefore Taguchi's method is adopted. Experiments are carried out according to combination levels indicated by L9 orthogonal array (Table 2) 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

Table 3. Levels and Factors used in Taguchi's Design

Factors	Length in mm	Diameter in mm	Thickness of steel tube in mm	% Recycled Concrete Aggregates
Level-1 (M20)	300	42.4	2.9	0
Level-2 (M40)	500	48.3	3.2	50
Level-3 (M60)	600	60.3	4.0	100

3.2. Main effect plots

After performing the experiments as per Taguchi's experimental design, main effects plots for ultimate axial load for steel tubes are plotted for tubes in filled with concrete of proportion M20, M30 & M40. A main effect is a direct effect on parameters on response and dependent variables. Typical main effect plots of parameters with respect to ultimate axial load and axial shortening for steel tubes are shown in Fig 4-5. It is plotted by considering mean of response at each level of parameters, as shown in table I. Maximum ultimate load was obtained for Length 300 mm, Thickness 3.2mm, Diameter 60.3mm and without any replacement of RCA for M20,M40& M60 but from Main effects plot Axial shortening is minim for 2.9mm thickness 600 mm length 60.3 diameter with a 50 replacement of recycled aggregates and, we observe that the rank of the parameter in response table show that Diameter of the column is the most influencing factor as deltas of means are calculated ranked it 1 of the Four factors considered in experimentation a typical response of Minitab in shown in Table 5 and the results obtained from experimentation are shown in Table 4.

Table 4. Results obtained from Experimentation

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 5. A typical Response from Minitab V16

Taguchi Analysis: Pu (20) versus Length (mm), Diameter (mm), Thickness (mm), % RCA

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Response Table for Signal to Noise Ratios
Larger is better

                                    Thickness
Level  Length(mm)  Diameter(mm)          (mm)  % RCA
1           48.88         44.77         46.48  48.03
2           46.13         46.78         48.02  46.86
3           47.16         50.63         47.68  47.29
Delta        2.75          5.86          1.54   1.17
Rank            2             1             3      4


Response Table for Means

                                  Thickness
Level  Length(mm)  Diameter(mm)          (mm)  % RCA
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
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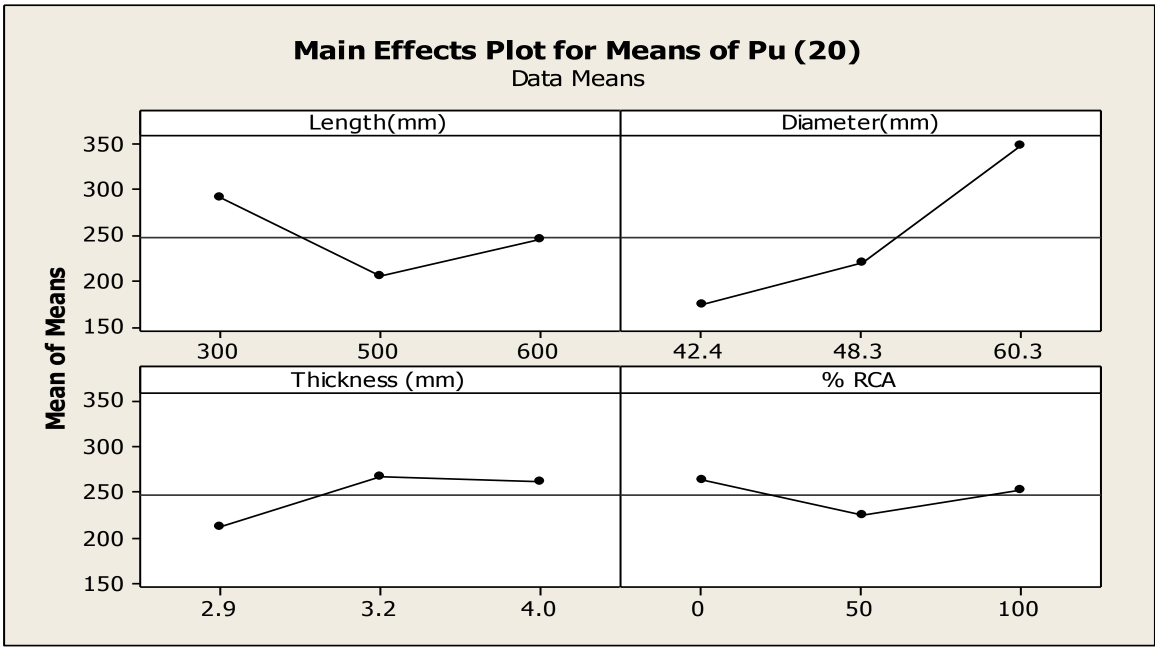

Figure 4. Main effects plot of mean of means for Pu (20)

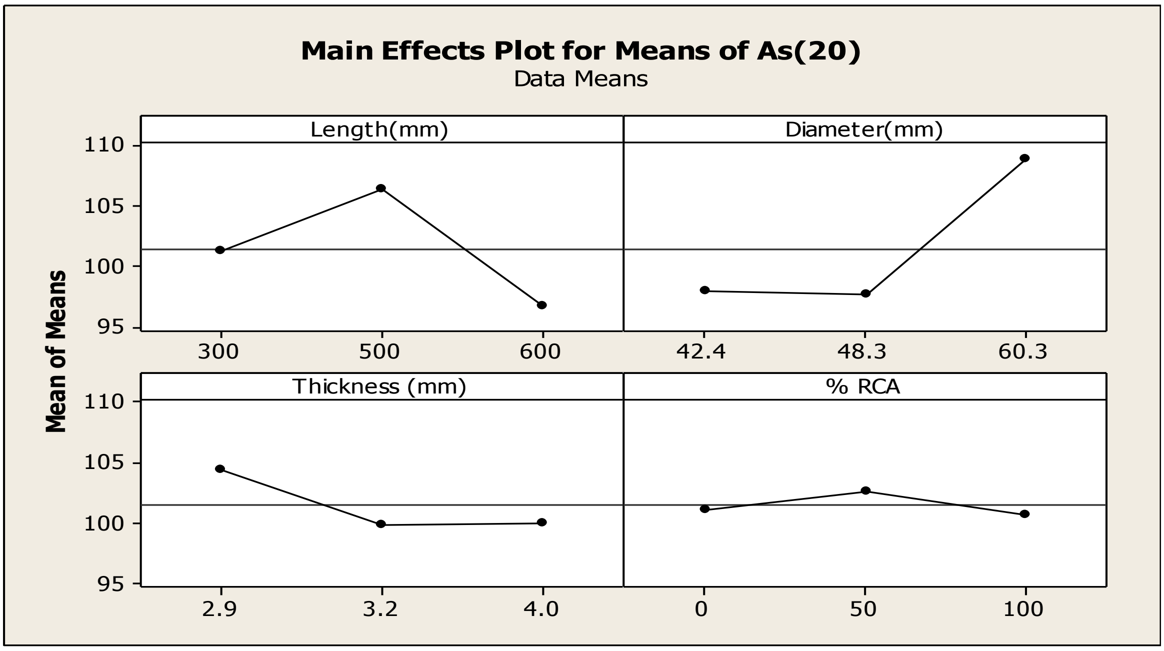

Figure 5. Main effects plot of mean of means for As (20)

3.3. Signal/ Noise Ratio

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 deceases 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. The S/N ratio characteristics can be divided into three categories given by Eq. (1) to (3).

- nominal is the best characteristic

$$\frac{S}{N} = 10\log\frac{\bar{y}}{s_y^2} \tag{1}$$

- smaller is the best characteristic

$$\frac{S}{N} = -10\log\frac{1}{n}\left(\sum y^2\right) \tag{2}$$

- and larger the better characteristic

$$\frac{S}{N} = -\log\frac{1}{n}\left(\sum\frac{1}{y^2}\right) \tag{3}$$

Eq. (1) is adopted for ultimate axial load and Eq. (3) is adopted for axial shortening a typical S/N ratio response is shown in Table 5. From the table we affirm that the conclusions from ANOVA and Main effects Plots, that Pu was obtained for L=300mm, D=48.3, T= 3.2 mm but the S/n ratio plots are shown in figs 6-7.

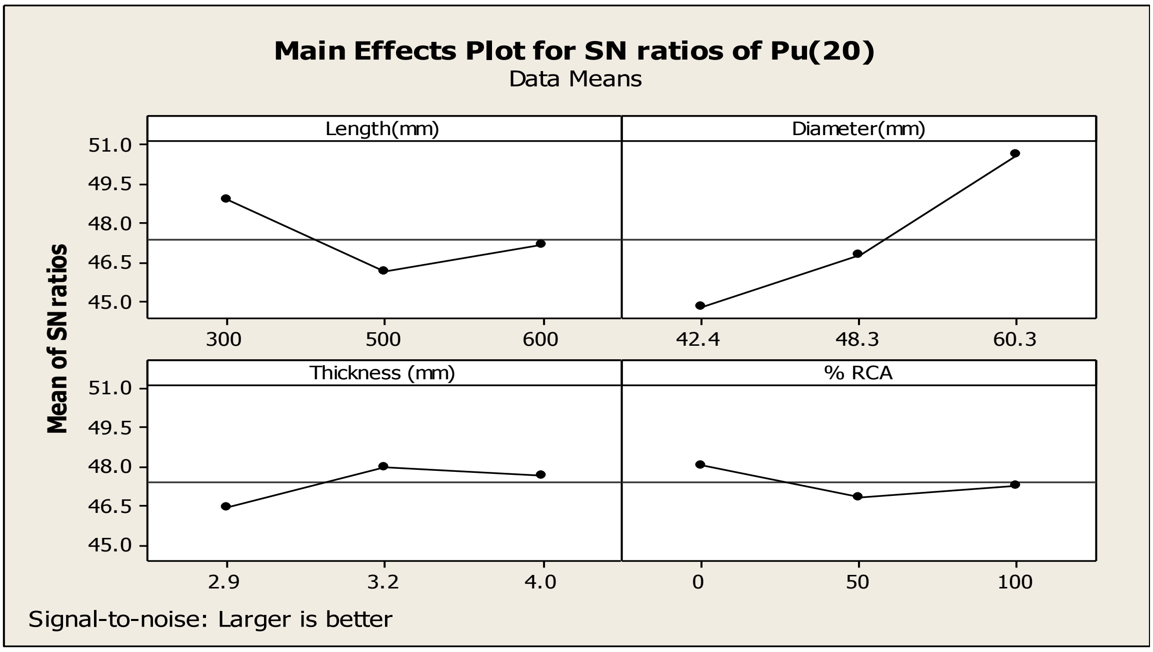

Figure 6. Main effects plot of mean of S/N ratio for Pu (20)

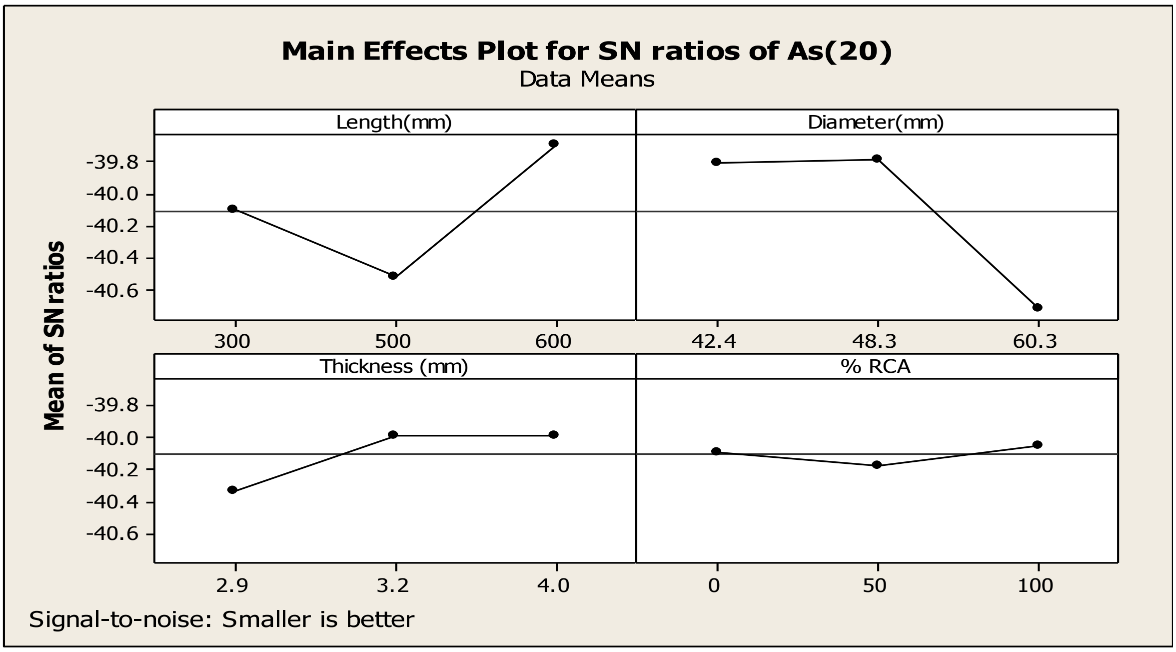

Figure 7. Main effects plot of mean of S/N ratio for As (20)

3.4. Analysis of Variance (ANOVA)

ANOVA is a statically tool which helps to reduce the error variance and quantifies the dominance of control factor. This analysis aids in justifying the effects of input changes on the responses in experiment. From ANOVA it was found that F &P could not be obtained because of asterisks.

3.5. Verification of Taguchi‘s method

After conducting the initial nine experiments (each in triplicate trial is 9X3=27), liner regression models are developed for all grade of infill but regression models of M20 M40& M60 are shown below (Eq. 4-10) to predict ultimate axial load and axial shortening for steel tubes at all three levels of circular tube samples. The equations are as in nomenclature table. These equations are used to predict the ultimate axial load capacity of samples used in the experimental program. To verify the accuracy of such prediction of load carrying capacity of samples the remaining experiments are conducted and a comparison of experimental values is made with predicted values it is observed that regression model based on initial nine experiments Pu and As not very well but reasonable well. A plot of experimental values vs. predicted values is plotted for all three levels steel tube. Time series plot of experimental values authenticates the same. The time series Plot is shown in Fig. 8.

- Pu(20) = - 270 - 0.191 Length(mm) + 9.86 Diameter(mm) + 34.3 Thickness (mm) - 0.107 % RCA (4)
- Pu(40) = - 307 - 0.206 Length(mm) + 12.4 Diameter(mm) + 19.3 Thickness (mm) - 0.263 % RCA (5)
- Pu(60) = - 243 - 0.215 Length(mm) + 11.7 Diameter(mm) + 10.7 Thickness (mm) - 0.133 % RCA (6)
- As (20) = 83.3 - 0.0096 Length(mm) + 0.660 Diameter(mm) - 3.10 Thickness (mm) - 0.0039 % RCA (7)
- As(40) = 296 - 0.175 Length(mm) - 0.72 Diameter(mm) - 18.9 Thickness (mm) - 0.047 % RCA (8)
- AS (60) = 88.7 - 0.0195 Length(mm) + 0.261 Diameter(mm) + 1.60 Thickness (mm) + 0.0203 % RCA (9)

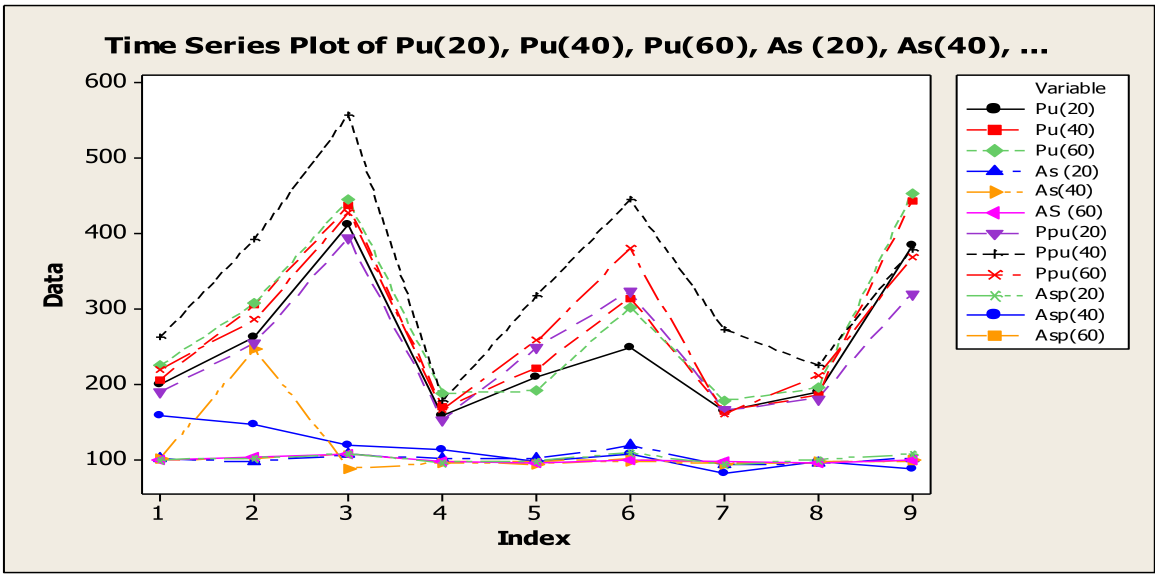

Figure 8. Time series plot of Predicted values and Experiment values

3.6. Interaction plots

Contour plots are plotted for ultimate axial load and axial shortening of all three levels of steel tubes are plotted of thickness, axial load and axial shortening and length is also plotted using Minitab v16. The plots explain that for thickness range of 3.2 -4.0 mm but is varying with different combination n in range Refer contour plots Fig 9.

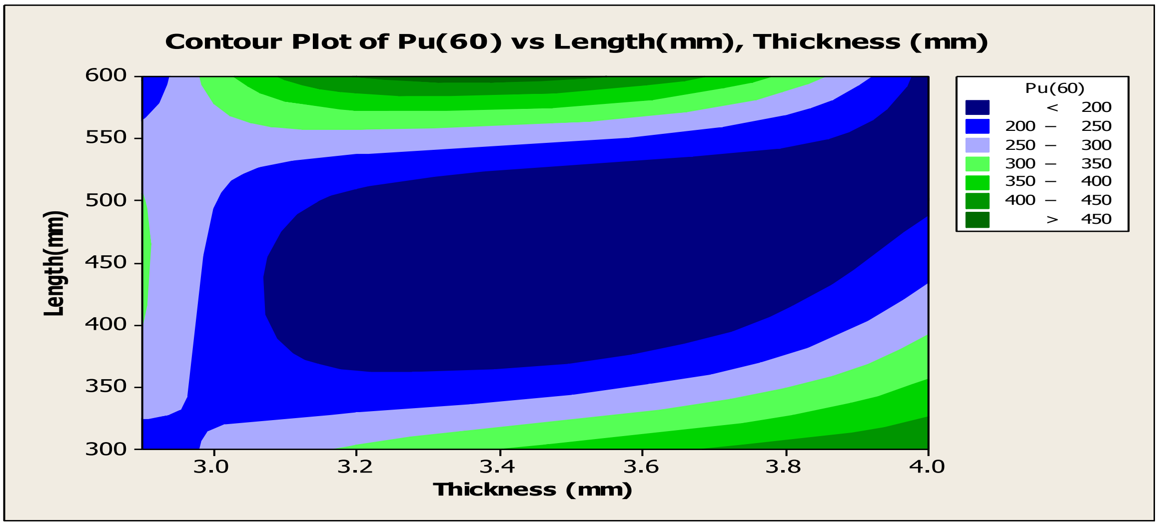

Figure 9. Specimens Contour Plot

4. CONCLUSION

- From Taguchi Analysis, for maximum Ultimate Axial Load carrying capacity using the response of means and response table of S/N Ratios, The predominate factors for Ultimate Axial load is **Diameter** of the Composite Colum for all grades.
- From Time Series plot we observe that Ultimate Axial load carrying capacity and Axial shortening of column can be well predicted.
- Maximum Load Carrying Capacity can obtained for **Length-300 mm, Diameter-60.3mm, Thickness-3.2mm and % RAC-0%**

- Minimum Axial Shortening can obtained for **Length-600 mm, Diameter-60.3mm, Thickness-4.0 mm and % RAC-100%**
- From this research work Parametric optimization and Factors influencing the response can be well predicted
- There is huge saving of cost and time in experimental work i.e. 88% of saving for our Experimental work

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