TRISHNAAH
quench your thirst for knowledge

ISSN Number : 2583-3901

Journal for Recent advances in Built Environment (JRAE), Vol- 3 Jan-2023

Taguchi based optimization of Bond Strength in CFST Columns using Grey Relational Analysis

Chethan Kumar S[1], Dr.N.S. Kumar[2]

[1]Assistant Professor, [2] Professor, Ghousia College of Engineering, Ramanagaram

Abstract:

Concrete filled steel tubes are extensively used in high rise structures and bridges. The characteristics such as ease of construction, maintenance, resistance to corrosion makes the concrete filled steel tubes a potential application in many structures to satisfy the durability criteria. Extensive research was carried out in the past decades on the behavior of CFST columns. The studies on bond strength were conducted by Virdi and Dowling. Experimental investigations were carried out on concrete filled steel tube columns with concrete using glass fibers, of different lengths and diameter. Taguchi's approach of DOE is adopted to save the time and cost of the experiments. The push-out tests were performed to investigate the effects of parametric variations. The optimization of parameters considering the bond strength in CFST columns using grey relational analysis is presented. The diameter, L/D ratio, percentage of glass fibers is considered for evaluating the bond strength. Those process parameters closely correlate with the selected performance characteristics in this study. Experiments based on the appropriate L9 OA are conducted. The normalized experimental results of the performance characteristics are then introduced to calculate the coefficient and grades according to Grey relational analysis.

***Keywords**: CFST, DOE, Pushout Test, Grey Relational analysis.*

1.0 Introduction:

Concrete Filled Steel Tubes are increasingly used in High-rise buildings and arch structures. The characteristics of aesthetic appearance, excellent durability, good seismic behavior and ease of construction as well as maintenance gives CFST a potential application in the onshore buildings, offshore platforms, bridges, and many more. Composite columns integrate the characteristics of steel and concrete materials, thereby providing high strength and stiffness, energy dissipation and economical. In composite columns , steel-concrete interface bond plays

*Corresponding Author : chethans0504@gmail.com

a major role in the regions at end connections where force transfer takes place. Past studies have indicated that a continuity of strains between steel and concrete can be assured if the concrete core and steel tube at the column ends are loaded simultaneously. In this case, the actual bond between the steel and the concrete has little or no significant influence on the performance of CFST. However, bond stress demand is excessively high where longitudinal shearing stresses are likely to be predominant.

Grey relational analysis was proposed by Deng in 1989, which is widely used for measuring the degree of relationship between sequences by grey relation grade. Several researchers adopted the grey relational analysis for optimizing the control parameters. To optimize the Bond Strength, Taguchi method with grey relational analysis is adopted. The following are the steps:

1. Identify the size of the tubes like length, diameter, thickness of the tube and grade of the concrete as infill.
2. Determine the number of levels for the Taguchi approach.
3. Select the appropriate orthogonal array.
4. Conduct the experiments based on the arrangement of the orthogonal array.
5. Normalize the experiment results of axial load and the deformation.
6. Perform the grey relational generating and calculate the grey relational coefficient.
7. Calculate the grey relational grade by averaging the grey relational coefficient.
8. Analyze the experimental results using the grey relational grade.

2.0 Experimental Datasheet:

The procedure for push out test to find the bond strength is described below. In this study a total of 27 specimens are tested using UTM under controlled loading of 0.2 kN/sec.

- CFST specimens are checked and prepared for the loading surface for horizontality.

- After the surface is made horizontal the specimen was placed in the UTM
- The solid steel cylinder is fixed in the loading frame and CFST column specimen to make sure the loading head is applied on the concrete.
- The initial load is applied on the concrete infill the load point is taken as zero with the dial gauge of accuracy of 0.01 is used to measure the slip of concert core.
- The load is applied and increased at a constant rate of 0.2 kN/sec is applied on the concrete to record the slip of concrete with respect to applied load on the CFST columns.
- Two cameras were used to record the slip with an accuracy of 0.01 mm and loading with an accuracy of 0.2 kN/sec. Once the CFST column fails under bond, the loading rate is increase to 2kN/min until the settlement reaches 30 mm.

Table:1 Pushout Test Results conducted on CFST columns for evaluating Bond Strength

Sl No	Grade of Concrete	Diameter of tube D in mm	Percentage of glass fiber	Thickness of the tube T in mm	L/D ratio	Pushout Load (Nu) KN	Bond Strength τu KN/mm^2
1	M20	33.7	0	2.6	12	66.36	1.5507
2		33.7	0.2	3.2	14	111.63	2.2360
3		33.7	0.4	4	16	108.8	1.9069
4		42.2	0	3.2	16	192.34	2.1498
5		42.2	0.2	4	12	39.45	0.5879
6		42.2	0.4	2.6	14	142.23	1.8168
7		48.3	0	4	14	111.69	1.0891
8		48.3	0.2	2.6	16	41.54	0.3544
9		48.3	0.4	3.2	12	99.2	1.1285
10	M25	33.7	0	2.6	12	58.35	1.3635
11		33.7	0.2	3.2	14	81.21	1.6266
12		33.7	0.4	4	16	96.7	1.6948
13		42.2	0	3.2	16	178.38	1.9938
14		42.2	0.2	4	12	50.84	0.7577
15		42.2	0.4	2.6	14	185.51	2.3697
16		48.3	0	4	14	82.05	0.8001
17		48.3	0.2	2.6	16	111.71	0.9531
18		48.3	0.4	3.2	12	54.762	0.6230
19	M30	33.7	0	2.6	12	60.22	1.4072
20		33.7	0.2	3.2	14	103.64	2.0759
21		33.7	0.4	4	16	92.7	1.6247
22		42.2	0	3.2	16	136.63	1.5271
23		42.2	0.2	4	12	54.71	0.8153

24		42.2	0.4	2.6	14	197.93	2.5283
25		48.3	0	4	14	104.83	1.0222
26		48.3	0.2	2.6	16	88.87	0.7582
27		48.3	0.4	3.2	12	134.85	1.5341

3.0 Grey Relation Analysis:

3.1 Data pre-processing:

The data pre-processing is the first step to be performed in the grey relational analysis to normalize the random grey data with different measurement units to transform them to dimensionless parameters. Thus, data pre-processing converts the original sequences to a set of comparable sequences. Different methods are employed to pre-process grey data depending upon the quality characteristics of the original data. The original reference sequence and pre-processed data (comparability sequence) are represented by $X_o^{(0)}(k)$ and $X_i^{(0)}(k)$, i=1,2,3,…..m; k=1,2,….,n respectively, where m is the number of experiments and n is the total number of observations of data. Depending upon the quality characteristics, the three main categories for normalizing the original sequence are identified as follows: If the original sequence data has quality characteristic as 'larger-the-better' then the original data is pre-processed as 'larger-the-best'

$$x_i^*(k) = \frac{x_i^{(0)}(k) - min\, x_i^{(0)}(k)}{max\, x_i^{(0)}(k) - min\, x_i^{(0)}(k)}$$

If the original data has the quality characteristic as 'smaller the better', then original data is pre-processed as 'smaller-the best':

$$x_i^*(k) = \frac{max\, x_i^{(0)}(k) - x_i^{(0)}(k)}{max\, x_i^{(0)}(k) - min\, x_i^{(0)}(k)}$$

However, if the original data has a target optimum value (OV) then quality characteristic is 'nominal-the-better' and the original data is pre-processed as 'nominal-the-better':

$$x_i^*(k) = 1 - \frac{|x_i^{(0)}(k) - OV|}{max\{max\, x_i^{(0)}(k) - OV, OV - min\, x_i^{(0)}(k)\}}$$

Also, the original sequence is normalized by a simple method in which all the values of the sequence are divided by the first value of the sequence.

$$x_i^*(k) = \frac{x_i^{(0)}(k)}{x_i^{(0)}(1)}$$

Where max $x_i^{(k)}$ and min $x_i^{(k)}$ are the maximum and the minimum values respectively of the original sequence $x_i^{(0)}(k)$. Comparable sequence $x_i^*(k)$ is the normalized sequence of original data.

3.2 Grey relational grade:

Next step is the calculation of deviation sequence, Δoi(k) from the reference sequence of pre-processes data $x_i(k)$ and the comparability sequence $x_i(k)$. The grey relational coefficient is calculated from the deviation sequence using the following relation:

$$\gamma\left(x_0^*(k), x_i^*(k)\right) = \frac{\Delta min + \xi \Delta max}{\Delta oi(k) + \xi \Delta max} \quad 0 < \gamma(x_0^*(k), x_i^*(k)) \leq 1$$

Where Δoi(k) is the deviation sequence of the refernce sequence $x_o^*(k)$ and comparability sequence $x_i^*(k)$. and comparibility sequence $x_i^*(k)$.

$$\Delta oi(k) = |x_0^*(k) - x_i^*(k)|$$

$$\Delta max = \underset{\forall j \in i}{max} \, \underset{\forall k}{max} |x_0^*(k) - x_i^*(k)|$$

$$\Delta min = \underset{\forall j \in i}{min} \, \underset{\forall k}{min} |x_0^*(k) - x_i^*(k)|$$

ξ is the distinguishing coefficient ξ ϵ [0,1]. The distinguishing coefficient (ξ) value to be chosen as 0.5. A grey relational grade is weighed average of the grey relational coefficient and is defined as follows:

$$\gamma(x_0^*, x_i^*) = \sum_{k=1}^{n} \beta k \gamma((x_0^*(k), x_i^*(k)), \sum_{k=1}^{n} \beta k = 1$$

The grey relational grade γ (x_o^*,x_i^*) represents the degree of correlation between the reference and comparability sequences. If two sequences are identical, then grey relational grade value equals unity. The grey relational grade implies that the degree of influence related between the comparability sequence and the reference sequence. In case, if a particular comparability sequence has more influence on the reference sequence than the other ones, the grey relational grade for comparability and reference sequence will exceed that for the other grey relational grades. Hence, grey relational grade is an accurate measurement of the absolute difference in data between sequences and can be applied to appropriate the correlation between sequences.

The experimental results for ultimate load (P_u), Axial shortening (Δ_s) listed in the Table 2. Typically, larger values of P_u and nominal values of Δ_s are desirable. Thus the data sequences have the nominal-the-better characteristic, the "nominal-the-better" methodology, was employed for data pre-processing.

Table 2: Orthogonal array L_9 (3^3) of the experimental runs and results

sl no	A	B	C	D	Bond Strength τu KN/mm^2 (M20)	Bond Strength τu KN/mm^2 (M25)	Bond Strength τu KN/mm^2 (M30)
1	1	1	1	1	1.5507	1.3635	1.4072
2	1	2	2	2	2.2360	1.6266	2.0759
3	1	3	3	3	1.9069	1.6948	1.6247
4	2	1	2	3	2.1498	1.9938	1.5271
5	2	2	3	1	0.5879	0.7577	0.8153
6	2	3	1	2	1.8168	2.3697	2.5283
7	3	1	3	2	1.0891	0.8001	1.0222
8	3	2	1	3	0.3544	0.9531	0.7582
9	3	3	2	1	1.1285	0.6230	1.5341

The values of the τu are set to be the reference sequence $x_o^{(0)}$ (k), k =1–3.Moreover, the results of nine experiments were the comparability sequences $x_i^{(0)}$ (k), i=1, 2... 9, k =1–3. Table V listed all of the sequences after implementing the data preprocessing. The reference and the comparability sequences were denoted $x_0^*(k)$ and $x_i^*(k)$, respectively.

Table: 3-a Data Processing Results

Comparability Sequence	Reference Sequence		
Run No	Bond Strength τu KN/mm^2 (M20)	Bond Strength τu KN/mm^2 (M25)	Bond Strength τu KN/mm^2 (M30)
1	0.6358	0.4240	0.3667
2	1.0000	0.5746	0.7444
3	0.8251	0.6136	0.4895
4	0.9542	0.7848	0.4344
5	0.1241	0.0771	0.0322
6	0.7772	1.0000	1.0000
7	0.3905	0.1014	0.1491
8	0.0000	0.1890	0.0000
9	0.4114	0.0000	0.4383

Table: 3- b Data Processing Results (contd…)

Comparability Sequence	Reference Sequence		
Run No	Bond Strength τu KN/mm^2 (M20)	Bond Strength τu KN/mm^2 (M25)	Bond Strength τu KN/mm^2 (M30)
1	0.36419	0.57601	0.63335
2	0.00000	0.42539	0.25558
3	0.17491	0.38637	0.51050
4	0.04580	0.21521	0.56563
5	0.87591	0.92290	0.96775
6	0.22277	0.00000	0.00000
7	0.60954	0.89861	0.85088
8	1.00000	0.81099	1.00000
9	0.58859	1.00000	0.56169

Table 4: Calculated Grey Relational Coefficient and Grey Relational Grade

Comparability Sequence	Reference Sequence				
Run No	Bond Strength τu KN/mm^2 (M20)	Bond Strength τu KN/mm^2 (M25)	Bond Strength τu KN/mm^2 (M30)	Grey Relational Coefficient	Grey Relational Grade
1	0.5786	0.4647	0.4412	0.4948	5
2	1.0000	0.5403	0.6617	0.7340	2
3	0.7408	0.5641	0.4948	0.5999	4
4	0.9161	0.6991	0.4692	0.6948	3
5	0.3634	0.3514	0.3407	0.3518	8
6	0.6918	1.0000	1.0000	0.8973	1
7	0.4506	0.3575	0.3701	0.3928	7
8	0.3333	0.3814	0.3333	0.3494	9
9	0.4593	0.3333	0.4709	0.4212	6

4.0 Conclusions:

1. The push out test conducted on CFST columns in this study showed that the bond strength is dependent on the type of concrete mixes is used as an in-fill material in the CFST column the reason is that the different adhesive force in different concrete due to the fines content variation in different type of concrete.
2. It was also found that the use of conventional concrete with Glass fibre as a in fill material in CFST columns is highly disadvantage, as it reduces bond strength.
3. Generally, as Length of the section increases, the bond strength increases. The highest Grey relational grade of 1.0000 was observed for the experimental run 5, shown in response table (Table No. 4) of the average Grey relational grade, which indicates that the optimal combination of control factors and their levels. D_2, T_1, and L/D_2 will gives nominal bond strength.
4. From this research work, parametric optimization and Factors influencing the response can be well predicted.

REFERENCES

1. Shakir-Khalil, H. (1991). ‘‘Bond strength in concrete-filled steel hollowsection.’’ Int. Conf. of Steel and Aluminum Struct., Elsevier Science
2. Abe H, Wakida T, Yuda T. Experimental investigation of bond strength of concrete – filled centrifugally cast stell tubes. In: Proceedings of 3rd international conference on steel–concrete, Fukuoka, Japan; 1991, p. 207–12.
3. Shakir-Khalil H, Hassan NKA. Push out resistance of concrete-filled tubes. In: Grundy P, Holgate A, Wong B, Balkema AA (Eds.), Proceedings of the sixth international symposium on tubular structures. 1994.
4. Parsley MA, Yura JA, Jirsa JO. Push-out behavior of rectangular concrete-filled steel tubes. Composite and hybrid systems, ACI SP-196. Farmington Hills, Michigan: ACI;2000.
5. Han L-H, Yang Y-F. Influence of concrete compaction on the behavior of concrete filled steel tubes with rectangular sections. Adv Struct Eng 2001
6. GB/T 228-2002. Metallic materials—tensile testing at ambient temperature. Chinese standard; 2002.
7. Gourley BC, Tort C, Denavit MD, Schiller PH, Hajjar JF. A synopsis of studies of the monotonic and cyclic behavior of concrete-filled steel tube members, connections and frames. Report No. NSEL-008. Urbana-Champaign: Newmark Structural Engineering Laboratory, Department of Civil and Environmental Engineering, University of Illinois; 2008.
8. Chen ZH, Qu XS,Wang XD, Sun RR, Li LM. Experimental study on the interface bearing capacity on concrete-filled square steel tube. J Harbin Inst Tech 2009

9. Antanas Kudzys, Romualdas Kliukas “Reliability Index Design In Reinforced Concrete Structures Of Annular Cross Sections”
10. N. Natural, Y. Yamaha, High speed machining of Inconel 718 with ceramics tools, Ann. CIRP 42 (1) (1993) 103-106.
11. M. Alauddin, M.A. EI Baradie, M.S.J. Hashmi, End milling machinability of Inconel 718, J. Eng. Manuf. 210 (1996) 11-23.
12. T.I. Elwardany, E. Mohammed, M.A. Elbestawi, Cutting temperature of ceramic tools in high speed machining of difficultto cut materials, Int. Journal of mechanical Tool Manufact 36 (5) (1996) 611–634.
13. E.O.Ezugwu, Z.M. Wang, A.R. Machado, The machinability of nickel-based alloys: a review, J. Mater. Process. Technol. 86(1999) 1-16.