EXPERIMENTAL INVESTIGATION ON BOND STRENGTH IN CONCRETE FILLED GALVANIZED IRON PIPE USING LIGHT WEIGHT CONCRETE WITH EXPANDED POLYSTYRENE BEADS

Suraj R G[1], Chethan Kumar S[2], Dr. N. S. Kumar[3]

[1]*Student, Dept. of Civil Engineering, Dayananda Sagar College of Engineering, Bengaluru, 560078, India*
[2]*Assistant Professor, Dept. of Civil Engineering, Dayananda Sagar College of Engineering, Bengaluru, 560078, India*
[3]*Professor and Director R&D, Ghousia College of Engineering, Ramanagara, 562159, India*

Abstract - *In this paper, bond behavior between the steel tube and light weight concrete containing expanded polystyrene beads as partial replacement for Coarse Aggregate (CA) is investigated. Replacement of CA is done in 0%, 10% and 20% in the concrete mix. For experimentation Taguchi's method is used, 27 specimens are prepared and bond strength is investigated by series of push out tests .The parameters considered for experimentation are- Diameter, Thickness, L/D ratio, concrete age, concrete type (nominal and light weight concrete). Bonding behavior is studied by load- slip curve. Effect of bond strength for different parameters is studied. The results showed that bond strength is decreased due to increase in EPS %, but there is decrease in weight of specimen. Lastly multiple linear regression analysis is done using Mini Tab software and regression equation is obtained for future predictions. .*

Key Words: **Bond strength, Expanded Polystyrene beads (EPS), Light Weight Concrete, Concrete filled steel tube, Push out test, Mini tab.**

1. INTRODUCTION

Concrete Filled Steel Tube (CFST) is a structural system where concrete is filled inside the hollow steel tube. The advantage of CFST is due to both the elements i.e. concrete and steel. In this project Expanded Polystyrene Beads (EPS) are used for partial replacement for coarse aggregate in concrete as 0%, 10%, 20%. So that the weight of the CFST is reduced and the main aim is to check the bond strength between concrete and steel. CFST columns are good at taking high load, they can be used in seismic area as they have high resistance to earthquake, they are good in resisting fire damage, due to the CFST stiffness it will take more time for occurring local bulking. Hollow steel section will act as permanent support to the concrete in other words as formwork and as reinforcement too.

Whenever a project is taken, the main aim is to complete the work quickly and the work should be economical, to attain this Industrialized Building System should be used, in which CFST are used for construction and used as one of the elements in construction and we will get all the advantages mentioned above.

Many authors strength have attempted to know the bond strength in CFST by push out test. So same test is used to know the bond strength between steel tube and concrete prepared by partial replacement of EPS beads for coarse aggregate. Different parameters like diameter, thickness, L/D ratio and percentage of replacement of EPS beads are altered. And these are compared with CFST with nominal concrete.

Zhong Tao, Tian-yi song (2016) et al.[1] showed that bond strength between the concrete and steel is known by experimental method. The procedure chosen is push out test. Series of push out test on different shape like square and circular CFST specimens were conducted.

The result obtained were bond strength in carbon steel was more than the steel.

To know the slip behavior and strain distribution all over height, Ran Feng (1), Yu chen (2) (2018) et al. proposed the paper in which 32 specimens were subjected to push out tests. The specimen were concrete filled steel tubes and shape was square. The study showed bond strength is inversely proportional to the concrete strength. Lastly author also came to conclusion that out of 100%, 70% of bond strength is due to friction of the interface elements, while other 30% bond strength is due to chemical adhesive force and mechanical interlock force.

To reduce self-weight of CFST M Abhilash, Sanyam Jhanjhari, P Parthiban, J Karthikeyan et al.[3] proposed a paper. To obtain this CFST containing concrete with light weight aggregates is used.To know which parameter will have high influence on Ultimate axial load and axial shortening , a statistical tool is used like ANNOVA. By using ANNOVA errors and variance are reduced.

Plastic waste is the main concern in this modern era. Plastic waste causes many serious problems. So to counter this, Awham Mohammed Hammed, Bilal Abdul- Fatah

Ahmed et al.[4]proposed the study in which recycled plastic aggregate is used as an alternative aggregate in concrete. By this there will be reduction in problems created by waste of recycled plastic.

To know about Light Weight Aggregate using EPS beads Chen Bing, Liu Jie, Chen Long, Zhu et al.[5] introduced EPS beads by totally or partially replacing Coarse Aggregate (CA) and Fine Aggregate (FA) in high performance concrete. The results were EPS beads concrete had high workability. Compressive strength decreases with increase in EPS beads volume. . EPS concrete have high shrinkage compared to nominal concrete. Water absorption decreases with increase in EPS volume.

2. AIM AND SCOPE OF STUDY

- To use light weight concrete using EPS beads in CFST columns.
- To find bond strength of CFST with light weight concrete as infill for different L/D ratio.
- To know the effects of cross section of steel tube on bond strength.
- To compare the results of bond strength of conventional CFST with CFST with light weight concrete.

3. METHODOLOGY

3.1 Taguchi's method: -

If the parameters are more the experiment becomes compex, time consuming and also non economical. To counteract this condition Taguchi method was developed by Dr. Genichi Taguchi of Japan. The main purpose of this method is to investigate how different parameters will affect the mean and variance of a process performance charateristic that defines how good the process is working.

3.2 Steps in Taguchi's method

1) Only a fraction of full factorial combination is required in a Taguchi's design or an Orthogonal array.
2) The design is balanced in orthogonal array means every factor levels are weighed equally.
3) Every factor are evaluated independently so that one factor do not influence in estimation of the other.
4) At each run or at each combination of control factors the complete set of noise factor is runned to carry out the experiment.
5) The response data of noise factor in the outter array are usually alligned in a row.
6) The column represents specific factor with two or more levels in the orthogonal array.
7) The table displays L9 (2**7) Taguchi's design. L9 means 9 runs, (2**7) means 7 factors with 2 levels each.
8) In this array orthogonal factors levels are weighed equally in the entire design. The table column represents the factors, the rows represents runs and each table cell represents the factor levels for that run.

4. EXPERIMENTAL PROGRAM

4.1 Material Properties

1. GALVANIZED STEEL TUBES-If a carbon steel sheet coated with zinc on both sides then it is called as Galvanized Steel. The galvanized steel can be produced by mainly two process-Continuous hot dipping and Electro-Galvanizing.

Hot dipping process – In this steel is dipped in hot molten zinc.
Electro-Galvanizing – In this zinc is deposited by electrolytic disposition.

Table 4.1 Mechanical and Physical properties of Galvanized steel tube

Density (x 1000 kg /m3)	7.8
Poisson's Ratio	0.27 – 0.30
Elastic modulus (Gpa)	210
Tensile Strength (Mpa)	445
Yield Strength	310
Elongation (%)	20

2. CONCRETE-Light Weight Concrete (LWC) with partial replacement of Coarse Aggregate (CA) with Expanded Polystyrene beads (EPS beads). Here CA are replaced by EPS beads with 0%, 10%, 20%. Here volumetric replacement is done for M40 grade is done.
3. EXPANDED POLYSTYRENE BEADS (EPS BEADS)-Structurally Polystyrene is a long hydrocarbon chain. And to this, phenyl group is attached to every other carbon atom. It is also called as vinyl polymer.

Fig 4.1- Expanded Polystyrene beads

4. Mix proportion-
Cement = 550 kg/m3
Water = 220 kg/m3
Coarse aggregate = 687 kg/m3
Fine aggregate = 972 kg/m3
W/C ratio = 0.4

4.2 Slump Test

Concrete slump test is the workability test which is used to determine workability or consistency of the concrete mix.

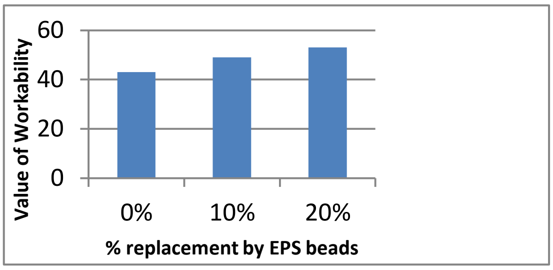


Chart 4.2- Graphical Representation of workability test

4.3 Compression Test

The compression test is conducted on 150 x 150 x150 mm cubes, for concrete age of 28 days after curing using Compression Testing Machine (CTM).

Table 4.3 – Compressive strength results

SL NO	Mix Design	% of EPS Beads	C/S Area of cube in mm2	28days compressive strength(n/mm2)
1		0	225	45.2
2		10	225	41.5
3		20	225	39.9
4	M40	0	225	45.1
5		10	225	41.4
6		20	225	40
7		0	225	46.9
8		10	225	40.2
9		20	225	37.6

Compressive strength of concrete cubes gradually decreases as increase in percentage EPS beads as replacement for Coarse Aggregates.

4.4 Loading set up for push out in UTM machine

Fig 4.4.1 Loading setup in UTM machine

All 27 specimens of Light Weight Concrete Filled Steel Tube and 3 Conventional concrete are tested in UTM for push out test. A small steel cylinder is used in between specimen and UTM machine because to transfer the load only to the concrete in CFST columns. Dial gauge of 0.01 accuracy is used and initial air gap is provided in CFST. The reason to apply load only to the concrete in CFST is to find the bond failure load between concrete and steel in CFST columns. Initial air gap is provided in CFST specimens to allow for the slip. The dial gauge is used to find the slip of the concrete infill with respect to steel and after that load slip curve is drawn to know the bond behavior of the concrete infill with steel in CFST columns.

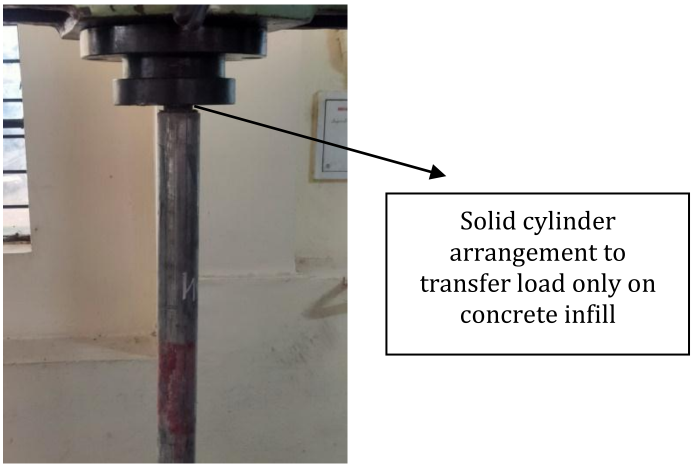


Fig 4.4.2 Solid cylinder arrangement for Load tranfer

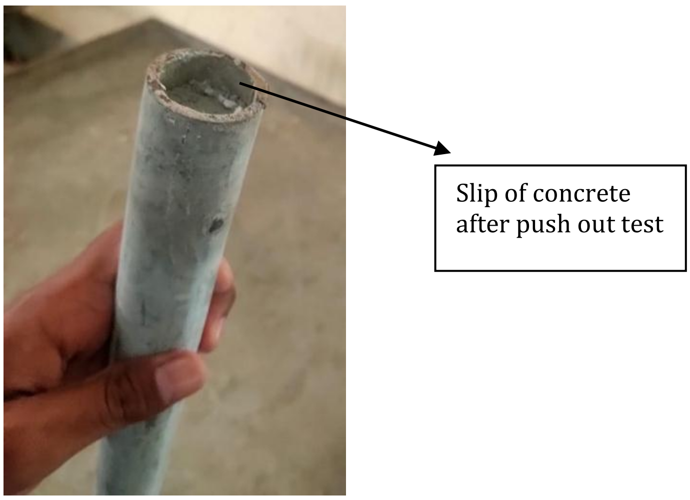


Fig 4.4.3 Specimen after push out test

4.5 Bond Strength Equation

$$\textbf{Bond Strength (□u)} = \frac{Pt}{\pi DL}$$

Where, Pt = Bond Failure load
D = Inner diameter of the steel tube
L = Length of interface of steel and concrete in CFST
□u = Bond Strength in Concrete Filled Steel Tube

Table 4.4 Tabulation of results

Test	Specimen label	D	T	L/D	Pt	□u
1	D33-L12-EPS 0%	33.4	2	12	88	2.478
	D33-L14-EPS 0%	33.4	3	14	117	2.949
	D33-L16-EPS 0%	33.4	4	16	144	3.376
2	D42-L12-EPS 0%	42.2	2	12	140	2.378
	D42-L14-EPS 0%	42.2	3	14	180	2.70
	D42-L16- EPS 0%	42.2	4	16	217	2.99
3	D48-L12- EPS 0%	48.3	2	12	179	2.280
	D48-L14- EPS 0%	48.3	3	14	222	2.494
	D48-L16- EPS 0%	48.3	4	16	271	2.769
4	D33-L12-EPS 10%	33.4	2	12	83	2.337
	D33-L14-EPS 10%	33.4	3	14	104	2.622
	D33-L16-EPS 10%	33.4	4	16	131	3.072
5	D42-L12-EPS 10%	42.2	2	12	134	2.276
	D42-L14-EPS 10%	42.2	3	14	166	2.498
	D42-L16-EPS 10%	42.2	4	16	210	2.895
6	D48-L12-EPS10%	48.3	2	12	172	2.191
	D48-L14-EPS10 %	48.3	3	14	212	2.381
	D48-L16- EPS10%	48.3	4	16	262	2.677
7	D33-L12-EPS 20%	33.4	2	12	81	2.281
	D33-L14-EPS 20%	33.4	3	14	103	2.596
	D33-L16-EPS 20%	33.4	4	16	123	2.885
8	D42-L12-EPS 20%	42.2	2	12	129	2.195
	D42-L14-EPS 20%	42.2	3	14	165	2.4831
	D42-L16-EPS 20%	42.2	4	16	203	2.801
9	D48-L12-EPS 20%	48.3	2	12	165	2.102
	D48-L14-EPS 20%	48.3	3	14	211	2.370
	D48-L16-EPS 20%	48.3	4	16	261	2.567

Where,
D= Inner diameter of steel tube
T=Thickness of steel tube
L/D=Aspect ratio
Pt. =Bond failure load
□u=Bond strength in N/mm2

5. Results and Discussion

1) Load-Slip curve

Load slip curves drawn from the push out tests indicates the behavior of bonding between steel and concrete infill in the CFST columns. From the graphs obtained it can be said that bond strength in CFST column is due to two main forces, Chemical adhesive force (micro locking) and frictional force in steel and concrete interface (macro locking).

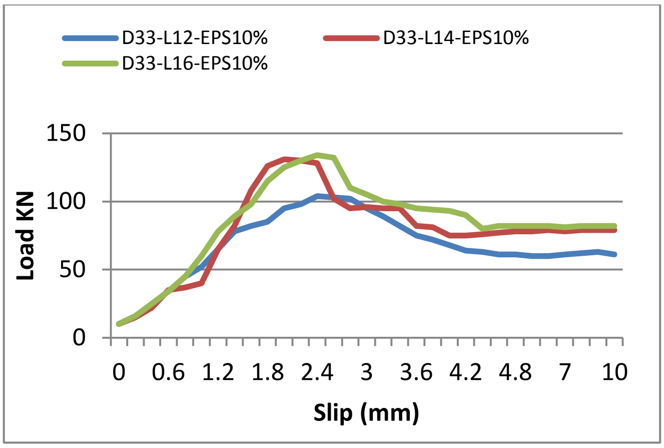
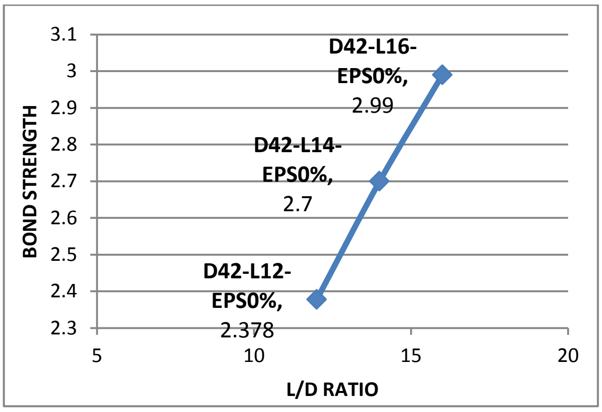
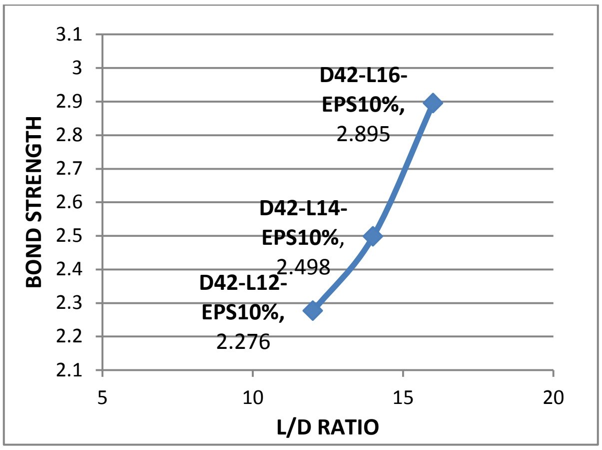


Chart -1: Load Slip Curve

2) Comparison of Bond strength vs L/D ratio





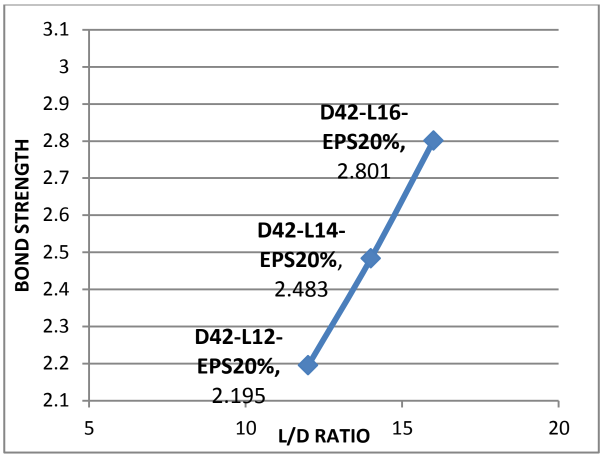
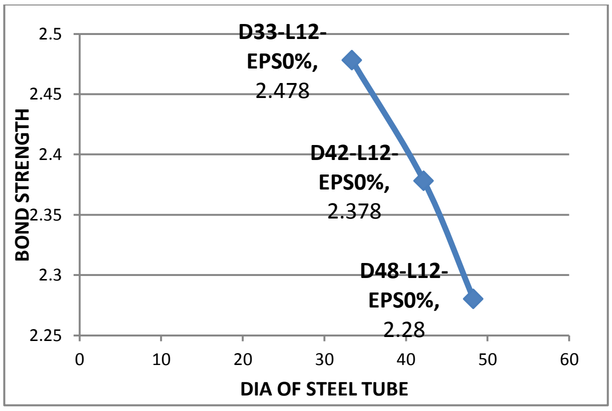
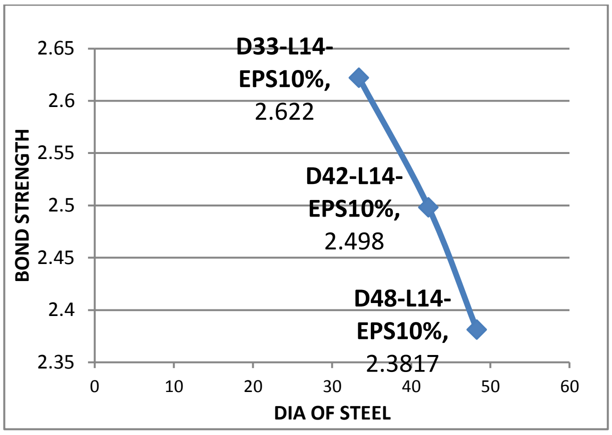


Chart 1: Bond Strength vs L/D ratio

From Chart 2, results show that as L/D ratio increases bond strength increases.

3) Comparison of Bond Strength vs Diameter of steel)





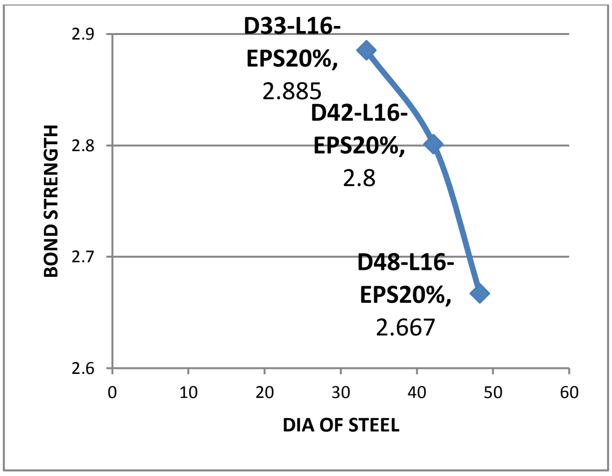


Chart 2 : Bond Strength vs Diameter of steel tube

From Chart 3, we can say that Diameter of steel is inversely proportional to the Bond strength. Therefore as the diameter of steel increases there is decrease in value of bond strength. Still experiments using higher diameter of steel is to be carried out to know the effect of diameter of steel to the bond strength.

4) Comparison of Weight to strength ratio of Nominal CFST with CFST containing EPS beads

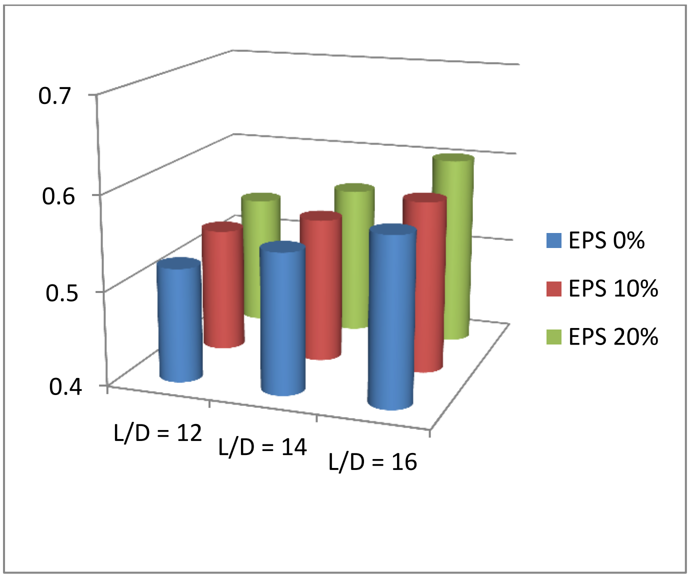


Chart 4- Comparison of Weight to Strength ratio of nominal CFST with CFST containing EPS beads

From above graph it can be concluded that weight to strength ratio increases with increase in percentage of EPS beads in concrete infill. By increase in percentage of EPS beads, bond strength decreases compared to nominal CFST (0% EPS beads) but at the same time there is decrease in the weight of the specimen. Thus resulting in decrease in dead load .The weight of CFST columns containing EPS beads in concrete infill will be less compared to the conventional CFST columns. Due to this CFST with EPS beads can be used in area where dead load is high, it is used to reduce the dead weight of the CFST columns and can be used in higher areas where live load coming to the CFST columns is low.

6. Multiple Linear Regression using Mini Tab software

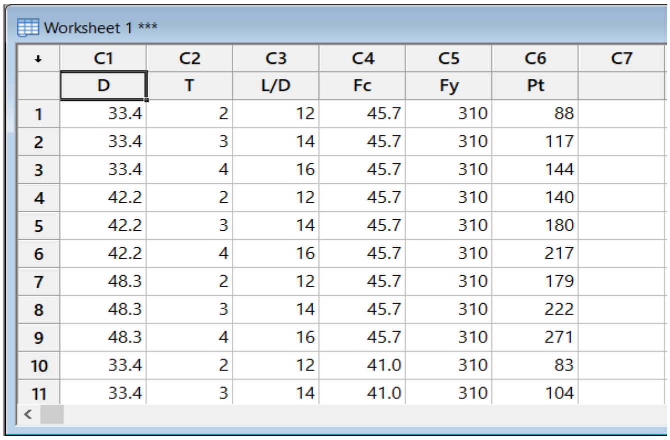
Minitab is a statistical package which can be used in statistical analysis. It is command and menu driven software. It was developed by Barbara F. Ryan, Thomas A. Ryan Jr and Brian L. Joiner in 1972 at Pennsylvania State University.

6.1 Steps in Multiple Linear regression

Step 1: Select independent variables and dependent variables. Both variables should be continuous.
Step2 : Regression model is built
Stat → Regression → select Regression → Fit Regression Model.

Step 3: "Regression" window is showed in screen.

Step 4: Enter dependent variables as responses and independent variables as continuous predictors.


Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7
	D	T	L/D	Fc	Fy	Pt	
1	33.4	2	12	45.7	310	88	
2	33.4	3	14	45.7	310	117	
3	33.4	4	16	45.7	310	144	
4	42.2	2	12	45.7	310	140	
5	42.2	3	14	45.7	310	180	
6	42.2	4	16	45.7	310	217	
7	48.3	2	12	45.7	310	179	
8	48.3	3	14	45.7	310	222	
9	48.3	4	16	45.7	310	271	
10	33.4	2	12	41.0	310	83	
11	33.4	3	14	41.0	310	104	

Fig 6.1 Worksheet entered

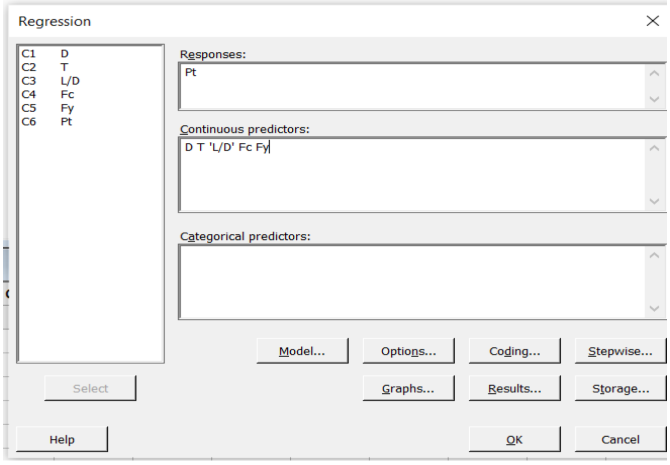


Fig 6.2 Selection of responses and continuous predictors

Step 5: Click "Graphs" and select "Four in One" and click "OK"

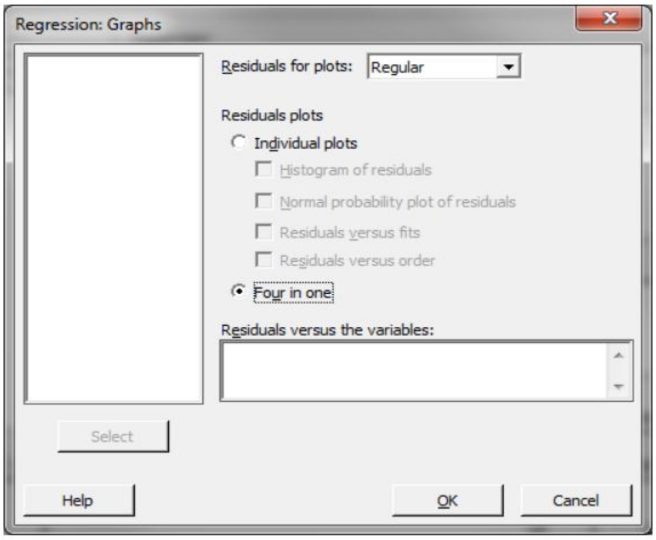


Fig 6.3 Selection of residual plots

Step 6: Select the "Storage" option and see that the tick of "Residuals" and "DFITS" and then "OK"

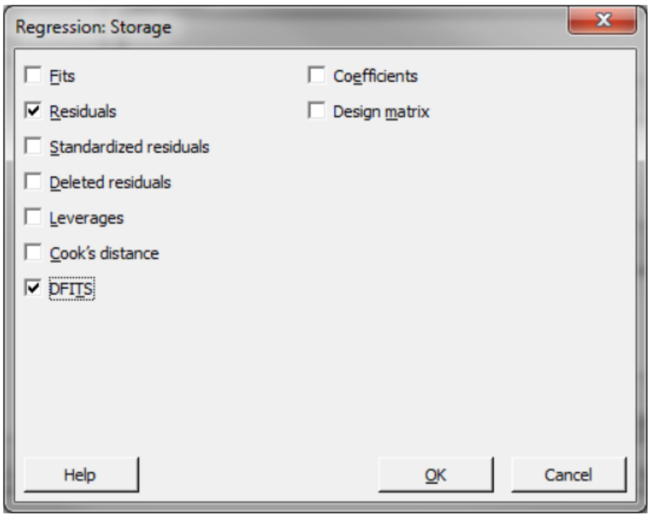


Fig 6.4 : Selection of regression storage

Step 7: Select "OK" in the window named "Regression".

Step 8: The regression analysis takes place and residual plots will appear.

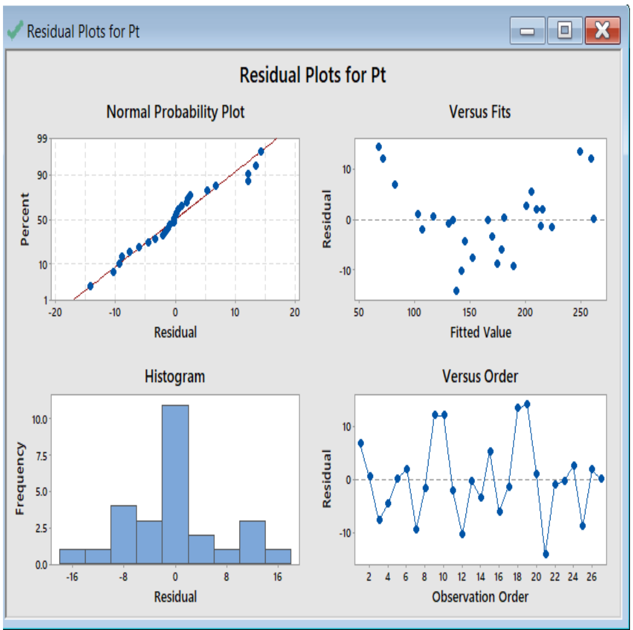
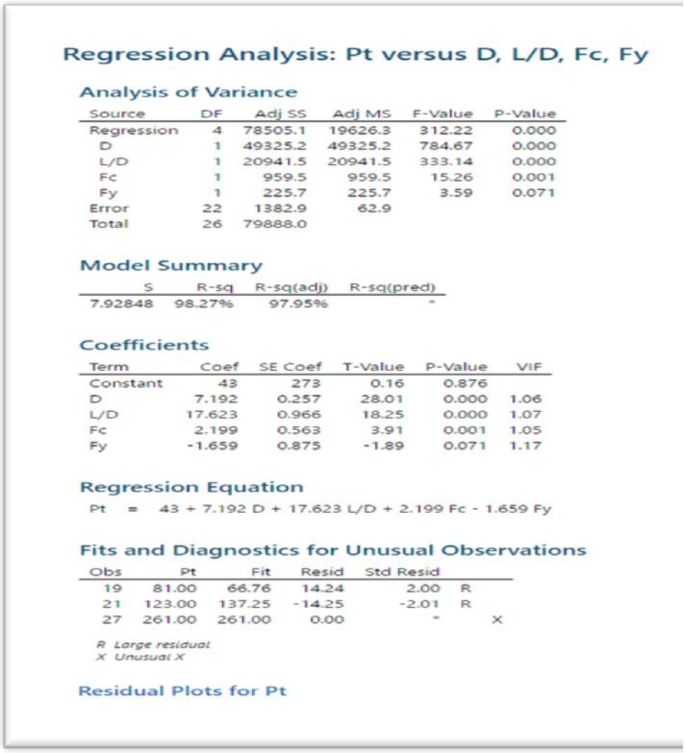


Fig 6.5: Residual plots for Pt

Step 9: Check if the whole model is statistically significant or not. If not, we should recheck the predictors or input new predictors.

Ho: The model is not statistically significant
H1: The model is statistically significant

In our experiment the p-value is much smaller than alpha level (0.15), hence we neglect the null hypothesis, and we conclude that the model is statistically significant.



Regression Analysis: Pt versus D, L/D, Fc, Fy

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	78505.1	19626.3	312.22	0.000
D	1	49325.2	49325.2	784.67	0.000
L/D	1	20941.5	20941.5	333.14	0.000
Fc	1	959.5	959.5	15.26	0.001
Fy	1	225.7	225.7	3.59	0.071
Error	22	1382.9	62.9		
Total	26	79888.0			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
7.92848	98.27%	97.95%	*

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	43	273	0.16	0.876	
D	7.192	0.257	28.01	0.000	1.06
L/D	17.623	0.966	18.25	0.000	1.07
Fc	2.199	0.563	3.91	0.001	1.05
Fy	-1.659	0.875	-1.89	0.071	1.17

Regression Equation

Pt = 43 + 7.192 D + 17.623 L/D + 2.199 Fc - 1.659 Fy

Fits and Diagnostics for Unusual Observations

Obs	Pt	Fit	Resid	Std Resid		
19	81.00	66.76	14.24	2.00	R	
21	123.00	137.25	-14.25	-2.01	R	
27	261.00	261.00	0.00	*		X

R Large residual
X Unusual X

Residual Plots for Pt

Fig 6.6 : Regression analysis

Step10: Check whether multicollinearity exists in model
Multicollinearity – This situation exists when two or more independent variables are correlated with each other in multiple regression model. This can be found out by referring to VIF (Variation Inflation Factor).

- If VIF is less than 5, then there is no multicollinearity.
- If VIF is greater than 5, then there is some multicollinearity.
- If VIF is greater than 10, then there is large multicollinearity.

How to solve the Multicollinearity

1. We should increase the sample size.
2. Broader range samples should be collected for some predictors.
3. Variables containing with high VIF and p-value should be removed.
4. Remove variables that are considered more than once.
5. Combine correlated to create new one.

In this experiment VIF values are less than 5 (Fig 7.2.6), hence there is no Multicollinearity.

Step 11: Interpretation of the regression equation
The multiple linear regression equation is obtained at the Regression analysis window.

Regression Equation (Referring to **Fig** 6.6)

P = 43 + 7.192D + 17.623 L/D + 2.199 Fc - 1.659 Fy

R square Adj=97.95%

97% of the variation can be explained by the predictor variables.

By using regression equation new predicted Pt values can be found out.

For Example:

Consider Specimen D33-L12-EPS 0%

For this, P_t (predicted) by using Regression Equation is given by

Pt = 43 + 7.192 D + 17.623 L/D + 2.199Fc – 1.659 Fy
=43+(7.192*33.4)+(17.623*12)+(2.199*45.7)-(1.659*310)
Pt= 80.8263 KN

Following this procedure for all specimen, we get predicted Pt

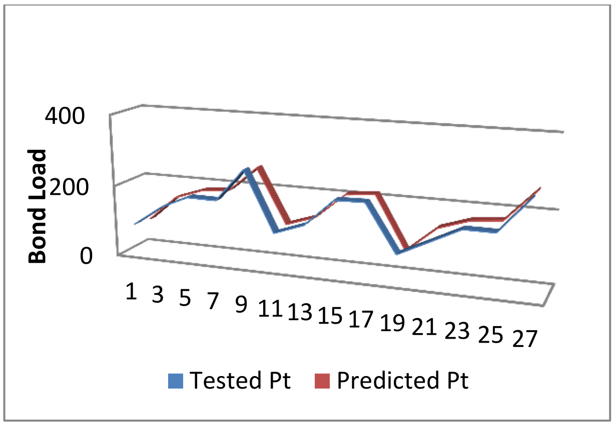


Fig6.7 Comparison of Actual Bond failure load with Predicted Bond failure load

7. CONCLUSIONS

Based on the experiments conducted following conclusions can be drawn

1. Weight of the CFST decreased due to introduction of EPS beads as partial replacement for Coarse Aggregate in concrete infill.

2. Usage of these CFST with EPS beads can be done where dead load is high (To reduce the dead load). And these CFST can be used in higher areas where live load acting is less.

3. From load slip curve obtained from push out test, it concludes that bond strength in CFST columns is due to two main forces. They are chemical adhesive force (micro locking) and frictional force in steel and concrete interface (macro locking).

4. Geometry of the CFST specimens has the significant effect on the bond strength between concrete and steel.
a) As Slenderness ratio (L/D ratio) increases, then there is increase in bond strength.
b) As diameter of CFST columns increases, then there is

decrease in bond strength.

5. Experiment is done by using small diameters of steel, so further experiments should be done by taking higher diameter and checking the effect of this on bond strength.

REFERENCES

[1] Tao, Z., Song, T. Y., Uy, B., & Han, L. H. (2016). Bond behavior in concrete-filled steel tubes. Journal of Constructional Steel Research, 120, 81–93. https://doi.org/10.1016/j.jcsr.2015.12.030

[2] Feng, R., Chen, Y., He, K., Wei, J., Chen, B., & Zhang, X. (2018). Push-out tests of concrete-filled stainless steel SHS tubes. Journal of Constructional Steel Research, 145, 58–69. https://doi.org/10.1016/j.jcsr.2018.02.016

[3] Abhilash, M., Jhanjhari, S., Parthiban, P., & Karthikeyan, J. (2019). Axial behaviour of semi-lightweight aggregate concrete-filled steel tube columns – A DOE approach. Journal of Constructional Steel Research,162. https://doi.org/10.1016/j.jcsr.2019.05.004

[4] Hameed, A. M., & Ahmed, B. A. F. (2019). Employment the plastic waste to produce the light weight concrete. Energy Procedia, 157(2018), 30–38.

https://doi.org/10.1016/j.egypro.2018.11.160

[5] Chen, B., Liu, J., & Chen, L. (2010). Experimental study of lightweight expanded polystyrene aggregate concrete containing silica fume and polypropylene fibers. Journal of Shanghai Jiaotong University (Science), 15(2), 129–137.

https://doi.org/10.1007/s12204-010-9550-3

[6] Abendeh, R., Ahmad, H. S., & Hunaiti, Y. M. (2016).Experimental studies on the behavior of concrete-filled steel tubes incorporating crumb rubber. Journal of Constructional Steel Research, 122, 251–260. https://doi.org/10.1016/j.jcsr.2016.03.022

[7] Lu, Y., Liu, Z., Li, S., & Li, N. (2018). Bond behavior of steel fibers reinforced self-stressing and self-compacting concrete filled steel tube columns. Construction and Building Materials, 158, 894–909. https://doi.org/10.1016/j.conbuildmat.2017.10.085

[8] Qu, X., & Liu, Q. (2017). Bond strength between steel and self-compacting lower expansion concrete in composite columns. Journal of Constructional Steel Research, 139, 176–187. https://doi.org/10.1016/j.jcsr.2017.09.017

[9] Patidar, H., Singi, M., Bhawsar, A., Student, M. T., & Indore, M. P. (2019). Effect of Expanded polystyrene (EPS) on Strength Parameters of Concrete as a Partial Replacement of Coarse Aggregates, (June), 3779–3783.

[10] Xiushu Qu, “Push-out tests and bond strength of rectangular CFST columns” publication ASCE, 2015

[11] Charles W. Roeder, “Composite Action in concrete Filled Tubes” publication ASCE Journal of Structural Engineering, Vol. 125, No. 5, May, 1999

[12] T.Aly, “Incremental Collapse Threshold for Pushout Resistance of Circular Concrete Filled Steel Tubular Columns” publication Elsevier Journal of Constructional Steel Research, 1 August 2009