Experimental Study on Bond Behavior of Steel Fiber Reinforced Self-Compacting Expansive Concrete Filled PVC Tubes

Meril Jose[1], Hanna Paulose[2]

[1]PG Student, Computer Aided Structural Engineering, Dept. of Civil Engineering, Mar Athanasius College of Engineering, Kothamangalam P.O, Ernakulam, Kerala, India
[2]Assistant Professor, Dept. of Civil Engineering, Mar Athanasius College of Engineering, Kothamangalam P.O, Ernakulam, Kerala, India

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Abstract – *Concrete Filled Tubular (CFT) column offers high bearing capacity, rigidity and ductility. The concrete core can stabilize and stiffen the tube to delay the local buckling. The composite action requires excellent bond between tube and concrete core. The present study focusses on bond behavoiur of steel fiber reinforced self compacting expansive concrete filled Poly Vinyl Chloride (PVC) tubes. The variables considered in the study are: (a) concrete type (self compacting concrete and steel fiber reinforced self compacting expansive concrete); (b) thickness of PVC tubes (2.5mm, 4mm and 6mm); (c)steel fiber volume percentage (0%, 0.5% and 1%). The results show that the bond strength of steel fiber reinforced self compacting expansive CFT PVC tubes is higher than self compacting CFT PVC specimens. The bond strength also increases with increase in the thickness of PVC tubes.*

Key Words: Concrete filled tubes, Self- compacting expansive concrete, Bond strength, Slip, Push-out.

1.INTRODUCTION

Concrete-Filled Tubular (CFT) columns have gradually become a central element in structural systems owing to their high bearing capacity, rigidity and ductility, desirable performance under seismic loading or fire conditions. All the superior structural properties of CFT columns are mainly due to the composite action of tube and concrete core. The concrete core can stabilize and stiffen the tube to delay the local buckling. Their composite action requires excellent bond behavior between tube and concrete core.

The structural advantage of CFT require the tube and the concrete to bond well to ensure they work together. In practice, this has been attained by relying on either shear connectors on the inside of the tubes or the natural bond between tube and concrete. This bond stress transfer is not well understood. Bond stress demand varied for different structural systems and different locations in a structure. Demand was always greatest in regions of geometric discontinuity such as connections and foundation supports.

Poly Vinyl Chloride (PVC) tubes has advantages such as low cost, lightweight and is easy to handle and install. It is not affected by corrosion or other forms of degradation; therefore, it is used as an alternative to the metal in many applications where corrosion can compromise functionality and increase maintenance cost. However, the study of concrete-filled PVC tube (CF-PVCT) composite columns are limited even though its advantages are many.

Self Compacting Concrete (SCC) offers a rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC ensures a high level of homogeneity, minimal concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. But shrinkage of SCC is higher than traditional vibrated concrete due to the increased cement consumption. Concrete shrinkage could be very adverse to the bond strength of CFST columns. Hence, SCC with a self-expansion behaviour is adopted to solve the problem.

Lu et al. (2018)[1] investigates the bond behavior of steel fibers reinforced self-stressing and self-compacting concrete filled steel tube (FSSCFST) columns. Test results show that the bond strength of FSSCFST specimens varies from 0.50 MPa to 2.51 MPa, which is generally higher than the self-compacting CFST specimens. Also, self-stress significantly improves the bond strength of CFST specimens, and the average improvement level is 42.7%.

Xu et al. (2009)[2] studied the expansion/shrinkage behaviors and bond carrying capacities of 17 short, pre-stressing concrete filled circular steel tube (PCFST) columns by means of expansive cement and three short, conventional concrete filled circular steel tube (CFST) columns are experimentally investigated. The results indicate that both concrete mixes and dimensions of the steel tube have important influence on expansive behaviors of PCFST specimens. The pre-stress in concrete core is a sensitive parameter to the bond strength as well as the load–slip relationship.

Lam et al. (2008)[3] presented a study on expansion and compressive strength of concrete with expansive additive. Expansion of expansive concrete developed within 3 days, after that it is constant or reduces slightly due to shrinkage.

Jamaluddin et al. (2016)[4] presents results of an experimental study for concrete column filled PVC tubes confined by plain socket with 5.8 & 6.8 mm thicknesses, 102 mm diameter and 100 mm depth. The axial load enhancement of PVC-concrete columns confined using plain socket shows an increment of 21.3% up to 55.2%.

2. EXPERIMENTAL PROGRAM

2.1 Test Specimens

Push-out tests were conducted on 36 CFT PVC tube specimens. Of these nine tubes were filled with normal SCC, another nine tubes were filled with expansive SCC and eighteen tubes were filled with steel fibers reinforced expansive SCC. All the specimens were of length 300mm and external diameter of 140mm. The parameters tested include concrete type (SCC and steel fiber reinforced expansive SCC); thickness of PVC tubes (2.5mm, 4mm and 6mm);steel fiber volume percentage (0%, 0.5% and 1%). Details of the specimens are listed in Table 1. The specimens are labelled individually as: A-t 2.5-0.5%, where 'A' stands for concrete mix, 2.5 stands for thickness of PVC tubes in mm and 0.5% represents the percentage of steel fibers to the volume of concrete.

Table -1: Details of Specimens

Specimen ID	Thickness (mm)	Length (mm)	Diameter (mm)	Steel Fibers (%)
A-t 2.5	2.5	300	140	0
A-t 4	4	300	140	0
A-t 6	6	300	140	0
B-t 2.5-0%	2.5	300	140	0
B-t 2.5-0.5%	2.5	300	140	0.5
B-t 2.5-1%	2.5	300	140	1
B-t 4-0%	4	300	140	0
B-t 4-0.5%	4	300	140	0.5
B-t 4-1%	4	300	140	1
B-t 6-0%	6	300	140	0
B-t 6-0.5%	6	300	140	0.5
B-t 6-1%	6	300	140	1

2.2 Material Properties

The thickness of PVC tubes were 2.5mm, 4mm and 6mm. The tubes were of length 300mm, external diameter 140mm and hence the aspect ratio is 2.14.

A concrete mix of M30 was used in this study. In order to obtain expansion in SCC, an expansive additive was used in concrete. Two concrete mixes were considered for study. The mix 'A' represents normal SCC and mix 'B ' represents expansive SCC, which includes normal expansive SCC and steel fiber reinforced expansive SCC. The fresh properties of SCC were tested and listed in Table 2.

Hooked end steel fibers were used to make fiber reinforced SCC. The steel fibers had a length of 30mm, diameter of 0.5mm, aspect ratio of 60 and density of 7850kg/m^3. The steel fibers were distributed randomly into the concrete mixtures and the percentages were 0%, 0.5% and 1% to the volume of concrete.

Table -2: Fresh Properties of SCC

Mix ID	Slump Flow (mm)	T500 (s)	V-funnel test s)	L-box test
A	670	4.5	9.6	0.86
B-0%	668	4.8	10	0.88
B-0.5%	660	6	12.4	0.92
B-1%	590	9.5	14.6	0.96

2.3 Specimen Preparation

The concrete was filled in the PVC tubes without any vibrations, and an air gap of 20mm was left at the bottom of the tubes to allow the slip between the tube and concrete core. After casting the specimens were covered by a hemp bag to maintain relative humidity of over 90% at room temperature for 28 days.

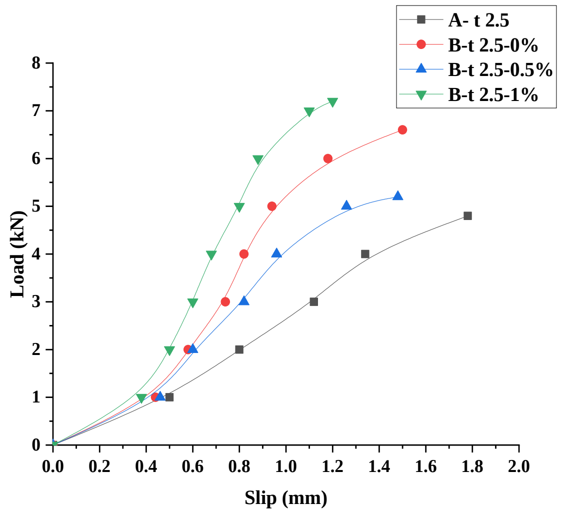
2.4 Test Setup

All the specimens were tested under Universal Testing Machine. By using a steel block having cross section slightly smaller than that of concrete core, the load was applied to the concrete core at the top and resisted by the tube alone at the bottom. The test was stopped when concrete core reached the loading plate. To obtain displacement, dial gauges were installed. The test setup is shown in Fig. 1.

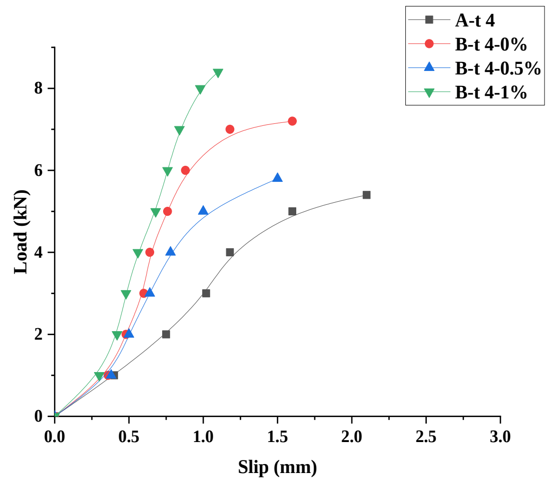
Fig -1: Experimental Test Setup

3. RESULTS AND DISCUSSIONS

3.1 Load versus slip (P-S) curves



(a)



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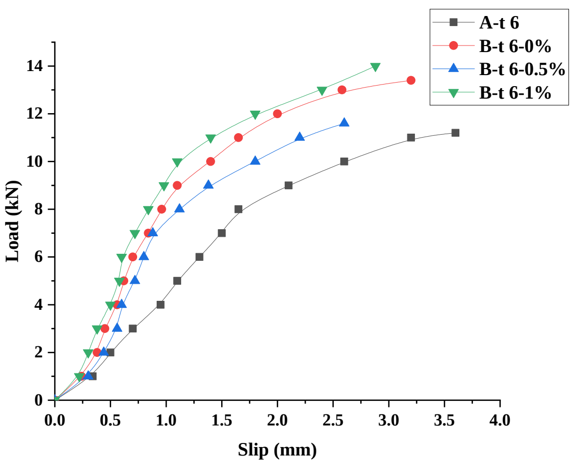
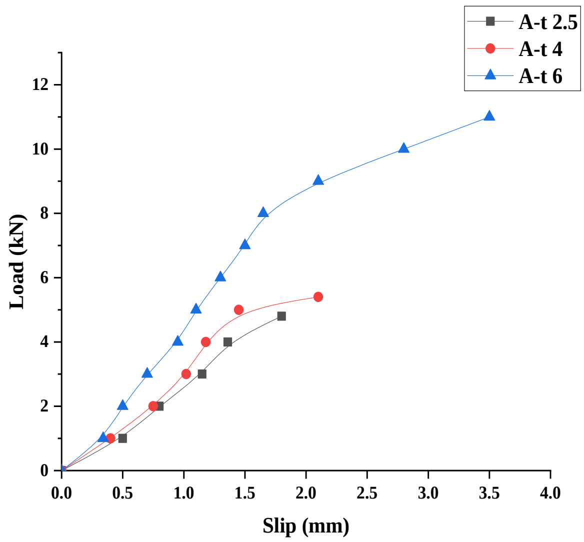


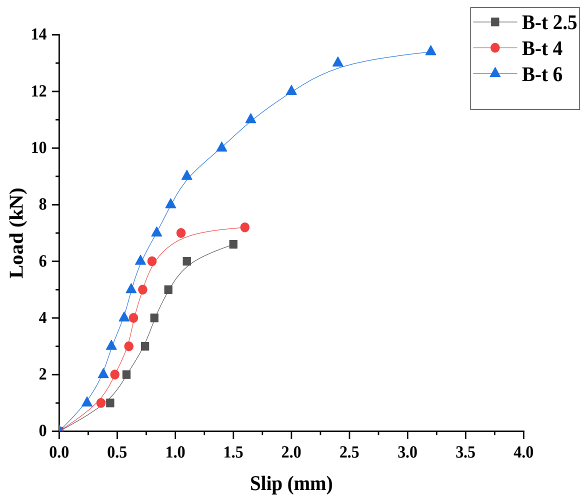
(c)

Chart -1: The effect of concrete type on P-S curves

Chart 1 shows the effect of concrete type on the load versus slip (P-S) curves for various thickness of tube. Expansive SCC (i.e, 'B' mix) shows higher ultimate load and a lower slip than normal SCC (i.e, 'A' mix). The reason is that, expansive SCC reduces shrinkage in concrete and makes concrete core more closer to the tube and thereby, provides more frictional resistance than normal SCC.



(a)



(b)

Chart -2: The effect of thickness of PVC tube on P-S curves

Chart 2 shows the effect of various thickness of PVC tube on P-S curves. With increasing thickness of tube, load for mix 'A' and mix 'B' specimens all shows an increasing trend. The reason is that thicker tube provides more confinement to concrete core and has a stronger stripping resistance.

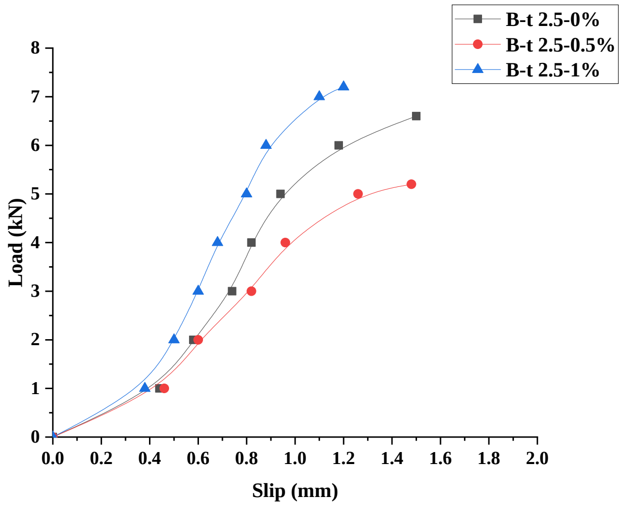


Chart -3: The effect of steel fibers on P-S curves

Chart 3 shows the effect of steel fiber volume percentage on P-S curves. The load firstly decreases at 0.5% of steel fibers to the volume of concrete and then increases at 1% of steel fibers to the volume of concrete. The reason is that at 1%, the steel fibers enhance the surface roughness of concrete core and leads to a higher load value. However at 0.5%, this beneficial effect is not remarkable and also, steel fibers restrain the expansion of SCC, thus reducing the peak load value.

3.2 Bond Strength

Bond strength (τ_u) is given by the formula;

$$\tau_u = \frac{P_u}{\pi DL}$$

In which P_u is the ultimate load in N, D is the inside diameter of the tube in mm and L is the bond length between concrete core and steel tube in mm.

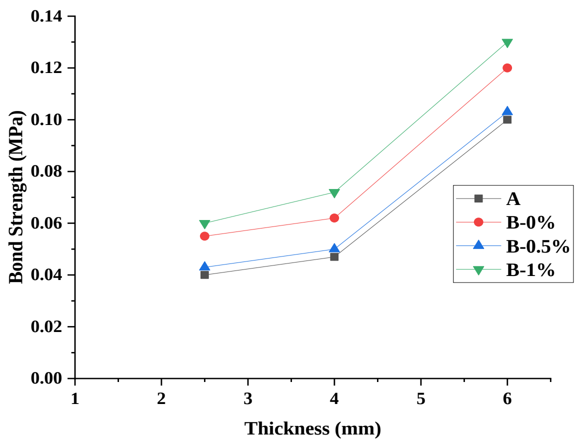


Chart -4: The effect of tube thickness on bond strength

Chart 4 shows the effect of tube thickness on bond strength for various mixes. It can be seen that, bond strength increases with increase in tube thickness for all the mixes. With tube thickness increasing from 2.5mm to 4mm, the average increment of bond strength is 16.62%. As the tube thickness increases from 2.5mm to 6mm, the average increment of bond strength is 130.2%. The reason is that thicker tube provides more confinement to concrete core and has a stronger stripping resistance.

It can also be inferred that, mix 'B' has higher bond strength than mix 'A'. The average increment of bond strength is 30.8%. This is because, the expansive behavior makes concrete core closer to the tube, increases the contact area and thereby leading to higher bond strength.

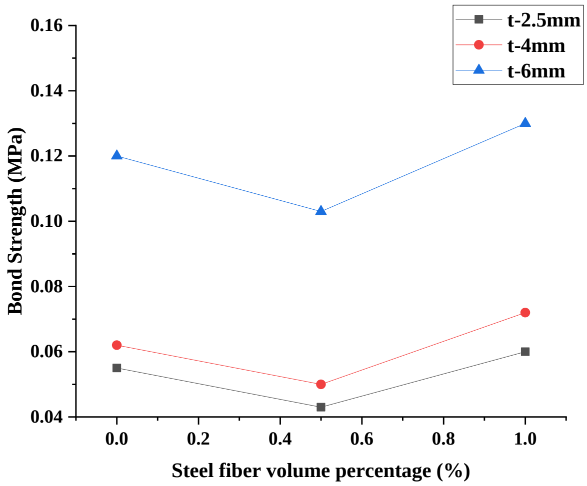


Chart -5: The effect of steel fiber volume percentage on bond strength

Chart 5 shows the effect of steel fiber volume percentage on bond strength for various thickness. It can be seen that, bond strength decreases at 0.5% of steel fibers and increases at 1% of steel fibers. By adding 0.5% of steel fibers to the volume of concrete, the average decrease in bond strength is about 18.44%. As the steel fibers volume percentage increases from 0.5% to 1%, the average increment in bond strength is about 36.58%.

4. CONCLUSIONS

The bond behaviour of self compacting expansive concrete filled PVC tube having thicknesses 2.5mm, 4mm and 6mm were studied. The following conclusions are drawn from the experimental results.

- The bond strength of CFT increases with increase in the thickness of the tube. With tube thickness increasing from 2.5mm to 4mm, the average increment of bond strength is 16.62%. As the tube thickness increases from 2.5mm to 6mm, the average increment of bond strength is 130.2%.

- Bond strength for expansive SCC is higher than normal SCC. The average increment of bond strength is 30.8%.
- The bond strength decreases at 0.5% of steel fibers and increases at 1% of steel fibers. At 0.5% of steel fibers, the average decrease in bond strength is about 18.44%. From 0.5% to 1%, the average increment in bond strength is about 36.58%.

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