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Flexural Strength Behavior of T-Shaped Beam-Column Joint with Varying Polypropylene Fibre

Nagari Vikas, Gude Rama Krishna, N. Sateesh

Abstract*: In times like this earthquakes are most commonly occurring phenomenon in every part of the world. It's crucial to make sure ductility of the structure is high, which is it should seamlessly distort non-elastically and diffuse forces with no major destruction. For any structural frames shear forces and bending moments are concentrated at the intersecting area. One of such areas is beam-column (B-C) joint. These are the most effected failure zones. The present work deals with experimental study of a T-shaped beam-column joint. From the literature, Polypropylene fibre have improved many desired properties of concrete such as flexural strength, breaking point etc. Therefore introduction of this fibre material into beam-column joint can improve joint properties. Previous studies on this fibre do not convey any important work that has been done on beam-column joint using this fibre, specifically pinned under axial force. In this study, 1/3rd scaled specimens of reinforced concrete (plane RC and RC fibres) T-shaped beam-column joint casted and tested for incremental loadings. All the specimens have been detailed by the provisions of IS: 13920, IS: 456. These specimens were tested by applying sequentially incremented repeated loads using Universal Testing Machine (UTM) of 100kN capacity. The results were correlated in different ways such as, flexural strength, hardness, force dissipation and ductility. Hence, in the present research this fibre material is used in T-shaped B-C joint to see the changes occurred in stiffness and flexural strength, of the joint.

Keywords*: Ductility, Beam-column joint, Polypropylene Fibre, Axial load, Failure zone.

I. INTRODUCTION

In recent times, earthquakes that have occurred have shown us the performance of reinforced concrete moment resisting frame structures and brought to light the significant poor functioning of beam-column (B-C) joints.

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***** Correspondence Author

Nagari Vikas*, Post-graduation Student, Civil Engineering, Institute of Aeronautical Engineering, Hyderabad, India. Email: nagarivikas009@gmail.com

Gude Rama Krishna, Associate Professor, Department of Civil Engineering, Institute of Aeronautical Engineering, Hyderabad, India. Email: venkatgude99@gmail.com

N. Sateesh, Professor, Department of Mechanical Engineering, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, India. Email: sateesh.nagari1@gmail.com

These joints in a Reinforced Concrete (RC) moment resisting frame are critical zones which transmit the loads efficiently among the joint elements (i.e. beams to columns). In Indian practice, the joint is usually neglected for specific design, which is limited to providing adequate anchorage for beam longitudinal reinforcement. In the analysis of RC moment resisting frames, these joints are generally expected to be inelastic in nature. This phenomenon is acceptable only if the frame is not subjected to earthquake loads. In the past earthquakes, most notably the 1999 earthquake in turkey and Taiwan, many catastrophic failures were attributed to B-C joints.

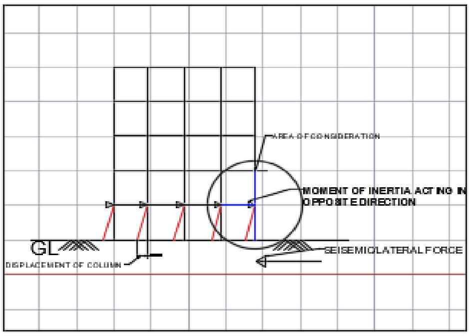

Fig. 1. Location of the T-shaped beam-column joint

The failure was caused by the poor design routine of beam-column joints and the in capacitance of the flexural members to transfer their loads to the adjoining members at the time of earthquake. This study involves, use of Polypropylene Fibre (PPF) as a micro reinforcement in 1/3rd scaled reinforced concrete (plane RC and RC fibres) T-shaped beam-column joint specimens. For test purpose a unit of beam-column joint as shown in Fig.1 is considered. The test samples was decreased to a scale of 1/3rd to suit loading arrangement and available test facilities. These were casted and tested for incremental loadings. All the specimens have been detailed by the provisions of IS: 13920, IS: 456. These specimens were tested by applying sequentially incremented repeated loads using Universal Testing Machine (UTM) of 100KN capacity. This study comprises of addition of various percentages of polypropylene fiber like 0.0%, 0.5%, 1.0%, 1.5% and 2.0%. PPF is added to the concrete dry mix. So as to develop concrete's hardness and decrease shrinkage cracks. Addition of PPF compensates any free water content in the mix and reduces segregation and bleeding of concrete mix, however higher PPF percentage decreases the mixing ability and drops the compressive strength of the concrete. Adding PPF lessens the concrete shedding and do not cause any significant surface cracks. It prevents cracked pieces of concrete from falling off the structure by holding them together as shown in the fig.7. The major task of fibres in a cement amalgamation is to resist cracks, improve the toughness and tensile strength, and increase the deformation properties of the matrix. Polypropylene Fiber Reinforced Concrete(PPFRC) is used in, drive ways, off shore structures, Overlays and toppings, roads and pavements, tanks and pools, ground supported slabs, Machine foundations etc.

II. LITERATURE REVIEW

1/3rd sized reinforced concrete beam-column joints with and without fibres were casted and are tested for maximum stiffness and ductility. The stiffness of the specimen containing polypropylene fibres has increased on a range of 27.9% to 43.2%. Ductility has also increased considerably on a range of 99.4% to 105%. So there was a delay in the propagation of crakes too [1]. Samples of different compositions of fibre have been tested so as to determine the best suited percentage of polypropylene fibre for concrete mix. Among 0%, 0.5%, 1.0%, 1.5%, 2.0% of polypropylene 0.5% have shown slightly higher results of ductility and toughness. In this research controlled water curing is determined best over irregular type of curing (left to air for curing). There has been a linear increment in the strength properties from 7 days to 28 days [2]. Even after considering the fact that cement is a binding material any unnecessary increase of the same can lead to deterioration of the compressive strength properties which is gained by existing fibre content. There are greater chances of loss of strength if, there is an increase of fibre content in correspondence with cement content. By this it is clear that the bonding strength is due to bondage between fibres and aggregates and not because of cement paste bonding [3]. In the matrix of concrete these fibres are acting as tie rods within the concrete particles so as to distribute the stress evenly into the matrix so that the structure maintains its integrity [4]. Any decrease in the amount of aggregates will decrease the bondage and furthermore the higher cement content couldn't bond with strands as polypropylene filaments are hydrophobic and lead to strength degradation bringing about quality loss of solid grid [5]. Reinforced Concrete with polypropylene mono filament fiber might be utilized as optional fortification however can't supplant the essential as the greatest quality increase is just about 13 % [6]. By use of Polypropylene filaments in cement ideal usage of materials is accomplished as well as the cost decrease is accomplished. Polypropylene strands decrease the water penetrability, settlements, plastic shrinkage, and carbonation complexity [7]. The question of low ductility of cement had been overcome by introducing of polypropylene strands to concrete mix. Split tensile strength and modulus of elasticity, compressive strength increased as compared with regular concrete [8].

III. MATERIAL PROPERTIES

A. Cement

The cementitious blend is prepared from concrete making materials and must accord to Indian Standards. Materials used to design the concrete mix with only cement, coarse aggregate, fine aggregate, and water is known as conventional concrete. The extra advantageous material that is included along the concrete making materials is polypropylene fiber. The concrete mix designed with polypropylene fibres is called as altered concrete. Following table gives the specification of the cement according to Indian Standard. 0.45 water to cement ratio has been selected. Ordinary Portland Cement (OPC) is used. 53 grade cement and specific gravity of 3.15 is selected.

Table-I: Physical Properties of Ordinary Portland Cement

S. No	Name of the test	Results obtained	IS 12269:1987 Specification
1	Initial setting time	140 min	Not less than 30 minutes
2	Final setting time	470 min	Not more than 600 minutes
3	Specific gravity	3.15	3.15
4	Soundness	3 mm	10mm
5	Consistency	33%	-
6	Compressive strength		
	7days	43.42 kg/cm^2	37 kg/cm^2 (Min)
	28days	60 kg/cm^2	53 kg/cm^2 (Min)
7	Fineness of cement	256 m^2/kg	225 m^2/kg (Min)

B. Fine Aggregate

Fine aggregate are of small size natural sand or crushed stone whose particles pass through 9.5mm sieve. These particles act as filler material between cement and coarse aggregate in dry state. River sand of 2.6 specific gravity and fineness modulus of 2.62 according to IS 383:1970 and passing through IS 4.75mm sieve is used.

C. Coarse Aggregate

Coarse aggregate (CA) are larger size stone made of granite rocks. They are inert filling material in the concrete mix. A 2.7 specific gravity CA has used. Coarse aggregate should be of gap graded passing through IS 20 mm sieve and retain on 4.75 mm IS sieve and according to IS 383:1970.

D. Steel

Steel is of many varieties among them are Fe250 (mild steel), Fe450, Fe500 and Fe550. In general for concrete reinforcements these grades of High Yield Strength Deformed (HYSD) steel bar are used. All this grades has been specified by Bureau of Indian Standards (BIS) IS 1786:2008. Here Fe500 steel is being used. The quantity 500 typically denotes the minimum Yield Strength (N/mm2) of the Bar to be suitable as Fe500.

E. Polypropylene Fibre

Polypropylene fibers are made using conventional polymerization of propylene gas. The Fig. 2 shows the actual image of the fibre. An artificial synthetic polymer, 12mm in length mono-filament macro fibre is used. 6.0 Denier x 12 mm cut length Polypropylene fibre. All the necessary properties of fibre is given in the following table.

Table-II: Physical Properties of Polypropylene Fiber

Test property	Technical data
Fibre Denier	6.0 +/- 10%
Breaking Tenacity [GPD]	4.4+/-10%
Breaking Elongation %	100+/-30
Wettability	Excellent in water
Dispersability	Excellent in water
Melting point [C]	165-170
Specific gravity	0.91

Fig. 2. Polypropylene Fibre

F. Water

Water is the main element, which forms a paste when mixed with the cement in dry state. It holds the aggregates to form a matrix. Upon mixing cement with water a process of hydration starts which results in hardening of the paste. Proper addition of water give good workability. Quantity of Water plays an important role in the production of perfect concrete because it determines the water to cement ratio. Water that is used should be clean potable water and should accord with Indian standards of IS 456:2000.

IV. EXPERIMENTAL PROCEDURE

A. Mould Preperation

At first a T-shaped mould was designed and made using locally available Aluminium Composite Panels (ACP) sheets, made of Aluminium Composite Material (ACM). The Fig. 3 shows how the moulds were shaped. These sheets are usually used in elevation of commercial buildings. These sheets have been cut to required dimensions and fixed to each other to form a T shape, using nut-bolt fittings. The dimensions of the beam-column joint is 600mm (L)*600mm (H) and a cross section of 150mm*150mm. Two moulds were prepared for convenience. Four HYSD bars of 500MPa yield strength with 8mm dia were used for reinforcement in beam and column as shown in Fig. 4. For lateral ties Fe250 (mild steel) bar of 4mm dia was used at 100mm center to center spacing as per IS:13920.

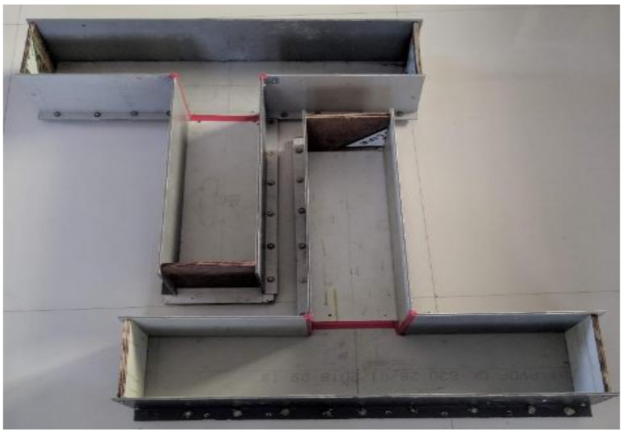

Fig. 3. Moulds of the Specimen

Fig. 4. Reinforcement Detailing

B. Mix Proportions and Casting of Specimens

For this work M30 grade mix was used and the mix ratio was 1: 1.75: 2.27 (table) and as per standards of IS: 456 and IS: 10262[23] [28]. There are five mixes for every mix fibre is added from 0% to 2% at an interval of 0.5%. The total number of specimens casted were 30 of which 24 specimens are Polypropylene Fibre Reinforced Concrete (PPFRC) and remaining 6 specimens are Conventional Reinforced Concrete (CRC). Each mixture contains 6 samples, the first three are tested after 7 days, and the remaining three are tested after 28 days of treatment, and their average value is noted. Fig. 5 shows how the casting and compaction the specimen was done. All samples were removed from the mould after 24 hours of casting. At that moment, the samples were named for recognition and placed inside water tank at a temperature (27^0 ± 2^0C). Following table gives the mix proportions that are used in this study.

Table-III: Mix Proportion of M30 Grade Concrete

S. No	Materials	Weight (kg/m3)
1	Cement	437
2	Water	197
3	Fine aggregate	768.6
4	Coarse aggregate	995
5	Water Cement Ratio	0.45
6	Polypropylene Fiber	1.5% Volume of Concrete

Fig. 5. Casting of the Specimen

C. Testing Method

The Universal Testing Machine (UTM) has a capacity of 100 KN, which is required to evaluate flexural strength, as shown in Fig. 6 is used. Hardened specimens are tested for their flexural strength. The size of the B-C joint used for testing is 150mmx150mm700mm (horizontal section), 150mmx150mm600mm (vertical section) as per IS 516:1959. Both conventional and altered concrete specimens are tested for flexural strength. A 7 days cured 0% PPF sample is placed in the UTM as a simply supported beam on horizontal section and a compressive sequentially incremented repeated loads is applied on top surface of the vertical section as shown in the fig. This sequentially incremented repeated load is applied until the sample fails and maximum flexural strength is noted. In the same manner other two samples of same composition are tested and an average flexural strength of all three samples were found. Similarly flexural strength of all other samples of 7 days and 28 days curing age are found. Fig. 7 shows how the fibres in the matrix holds the concrete particles together to avoid sudden failure of the specimen.

Fig. 6. Testing of the Specimen under UTM

Fig. 7. Strands of the Fibres holding the matrix to prevent brittle failure

V. RESULTS AND DISCUSSION

A. Flexural Strengths of Conventional Concrete and Altered Concrete:

All thirty T-shaped reinforced concrete beams (6 conventional 24 altered) cured for 7 days and 28 days were tested to find the ultimate load carrying capacity. The following expression gives average modulus of rupture (flexural strength).

$$Fcr = PL / BD^2 \quad (1)$$

Where Fcr = modulus of rupture

P = ultimate load in KN

L = length of the beam in m

B = average width of the specimen in m

D = average depth of the specimen in m

All the beams are tested in UTM to find the ultimate load carrying capacity which are subjected sequentially incremented repeated loads. The Fig. 8 represents result of the test conducted on conventional reinforced concrete cured for 7days. Considering ultimate load carrying of the beam (i.e 115.55KN) flexural strength is found using equation 1. The flexural strength is found as 23.96N/mm^2. Fig. 8 shows how the loads were acted upon the specimens.

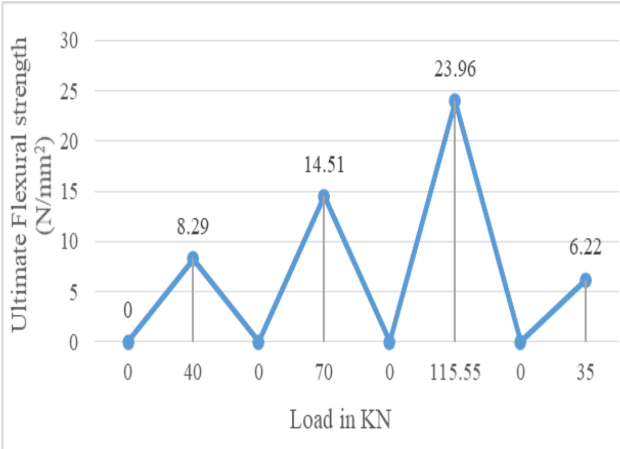

Fig. 8. Ultimate Flexural Strength of the Conventional Reinforced Concrete of 7 Days Specimen

Similarly all other 29 beams are tested and their corresponding flexural strengths are found. Average value of flexural strength is considered from three similar specimens tested. The Fig. 9 shows flexural strengths of conventional (0% PPF) and altered reinforced specimens (0.5%PPF, 1.0%PPF, 1.5%PPF, and 2.0%PPF) cured for 7 days and 28 days. From this graph it is clear that as the percentage of PPF increases flexural strength of the beam increases from 0% to 1.5% PPF and decreases further. Same phenomenon is observed in the specimens cured for 7 days and 28 days. The decrease in the flexural strength after 1.5% PPF is because, polypropylene fibre occupying in more volume in slurry present in the concrete mix. Hence resulting in weak bonding inside the matrix.

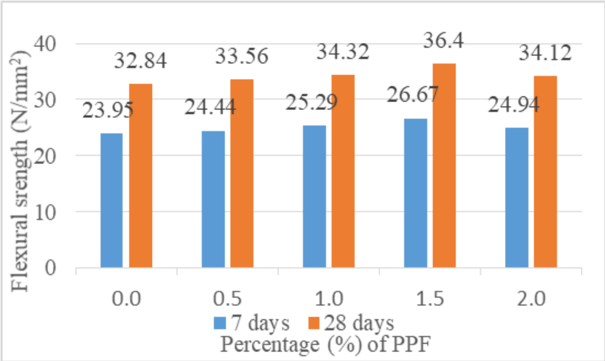

Fig. 9. Flexural Strength of the Different % of PPF Specimens at 7 Days and 28 Days

The variation of flexural strength w.r.t increase in % of PPF cured for 28 days is shown in Fig. 10. The percentage of increase in the flexural strength for concrete with 0.5% PPF compared to conventional concrete is 2.19%, similarly for 1.0% PPF the increment is about 4.5%, for 1.5% PPF it is 10.84% and lastly for 2.0% PPF it is 3.89%. The maximum value of flexural strength is observed in the specimen containing 1.5% PPF cured for 28 days.

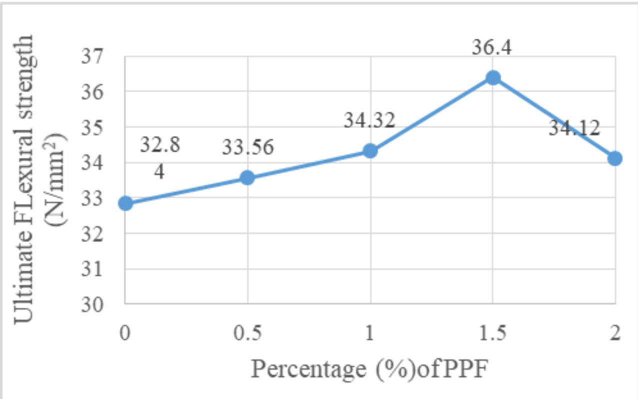

Fig. 10. Ultimate Flexural Strength of the Different % of PPF Specimens at 28 Days

VI. CONCLUSION

From the tests performed the following conclusions have been made:

1. Even when low volume percentage of PPF are mixed in concrete it will reduce the moisture loss and early age shrinkage of the mix.

2. While performing the research, it was observed that addition of PPF resulted in decrease of workability of fresh concrete mix. Execution of standard slump cone test determined the low mixing ability of fresh mix of concrete. Addition of increasing volume percentage of PPF into the mix concluded that there will be a comparable decrease in the workability of the mix. It was difficult to compact the concrete mix when the volume of PPF increased above 1.0% and it became considerably stiff. On the other hand segregation and bleeding in the concrete mixture were reduced.

3. By mixing PPF to the mix, enhancements in the behavior of the flexural strength are identical to that of tensile strength. We can therefore conclude that for both flexural strength and tensile strength the optimal value of PPF is 1.5%.

4. After 28 days of curing, conventional concrete and altered concrete are tested for flexural strength. Performance of the flexural strength of altered concrete was better over conventional concrete.

5. So as to increase the toughness of concrete PPF is added to the mix. This helps in formation of only top surface cracks even specimen fails.

6. The working of Fibre Reinforced Concrete (FRC) is governed by the type of the fibers used. Insertion of polypropylene fibers reduces the water penetrability. Because of its high modulus of elasticity it also enhances the flexural strength. Post the formation of cracks, as the fibers are pulled out, energy is absorbed and cracking is reduced.

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AUTHORS PROFILE

Nagari Vikas, completed his B.Tech from Vardhaman College of Engineering, Kacharam, Shamshabad, Hyderabad, India. Currently studying M.Tech in Institute of Aeronautical Engineering, Dundigal, in Structural Engineering in Department of Civil Engineering, Hyderabad, India.

Gude Rama Krishna graduated in Civil Engineering from Osmania University, Hyderabad, India. Completed his maters from JNTUH, Hyderabad, India. He is an associate professor from Institute of Aeronautical Engineering, Department of Civil Engineering, Hyderabad, India and obtained 15 years of research and industrial experience. Four of his research papers were published in international journals. He is pursuing PhD from Osmania University, Hyderabad, India. He is a Life member of Indian Society of Technical Engineering (ISET).

N. Sateesh Professor and Head of the Mechanical Engineering department, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, India. He graduated in Mechanical Engineering from Nagarjuna University AP, 1992. He has done his master degree from JNTUH, Hyderabad 2002 in CAD/CAM specialization. He is a PhD holder in Mechanical Engineering from Osmania University, Hyderabad, 2010He has published more than 37 papers in international journals and conferences. He is guided 12 M.Tech students. Guiding 2 M.Tech and 2 Ph.D students.