# Effect of Corner Radius on Confinement Effectiveness of GFRP and Lateral Ties Confined Polyolefin Fibre Reinforced Concrete Prisms under Monotonic Axial Compression

**S.Palanivel[1] M.Sekar[2] and N.Subramanian[3]**

[1]Associate Professor, Pondicherry Engineering College, Puducherry, India Ph: +919443956145 e-mail: spalanivel@pec.edu
[2] Former Professor and Dean, College of Engineering Guindy, Anna University, Chennai, India
& Principal, SRM Easwari Engineering College, Chennai, India Ph: +919789996247 e-mail: vimunasekar@gmail.com
[3]Consultant Civil Engineer, Maryland,USA e-mail: drnsmani@yahoo.com

## ABSTRACT

In testing the fibre wrapped concrete specimens under compression, the failure of the GFRP wraps is observed at or near a corner in all the specimens, mainly due to stress concentration. This may be expected since the prism's sharp edges are not rounded off. In order to avoid stress concentration, an attempt is be made to round off the sharp corners. To further study this problem, this research undertook compressive testing to investigate the effect of the corner radius on the strength and ductility of the FRP confined concrete prisms. This paper reports a series of tests on glass fiber reinforced polymer (GFRP) confined concrete prisms. A total of twenty three prisms of size 150 × 150 × 300 mm were tested under the strain control rate of loading. The primary variables in the investigation were the corner radius, transverse jacket, spacing of laterals and volume fraction of the polyolefin fibers. The results show that the smoothening of the edges of a square cross-section plays a significant role in delaying the rupture of the FRP composite at these edges, and the efficiency of the FRP confinement is directly related to the radius of the cross section edges. Furthermore, it is revealed that the confinement provided by a jacket with rounded corner radius is not only increasing the strength of the concrete prisms, but significant in increasing the ductility of the concrete prisms.

## INTRODUCTION

The behaviour of the fiber reinforced polymer (FRP) confined concrete in circular cylinders has been extensively studied, but much less is known about the concrete in FRP confined square prisms, in which the concrete is non-uniformly confined and the effectiveness of the confinement is much reduced. Most published research indicates that a certain degree of effective confinement (partial confinement) is provided by a jacket with sharp corners(i.e., a zero corner radius). It was observed in the previous studies that the failure of all confined prisms is marked by the rupture of the GFRP. It occurs prematurely for a stress level appreciably lower than the ultimate strength of the composite. The failure of the square specimens always starts at one of the corners, proving that the stress concentration occurs at the corners.

The GFRP wrapping of concrete increases the strength and ductility of the concrete, but this phenomenon is strongly influenced by the cross sectional shape. It is expected that the confinement effectiveness of the GFRP wrapping is less in the case of a sharp square section (corner radius = 0 mm) compared to a square cross-section with rounded corners (corner radius = 5 to 25 mm). This is due to a high concentration of stresses at the corner of the square section with sharp edges, and also to the partial effectively confined concrete core in this case compared to those with rounded corners. Glass fiber wrapped specimens typically failed by a fracture of the GFRP composite at or near the corner of the specimens due to the stress concentration in those regions. In all the cases, the prisms' failure was the result of the rupture of the FRP jacket. For most of the wrapped prisms, it was associated with concrete crushing at or near the prisms' ends and marked by wraps rupturing in the circumferential direction. Approaching failure load, the appearance of white patches was found, which indicated the yielding of the E-glass and resin. After failure, disintegrated concrete was found. The failure of the GFRP wraps was observed at or near a corner in all the specimens, mainly due to stress concentration. This may be expected since the prism's sharp edges were not rounded off. In order to avoid stress concentration, an attempt is be made to round off the sharp corners.

To further study this problem, this research undertook compressive testing to investigate the effect of the corner radius on the strength and ductility of the FRP confined concrete prisms. This paper reports a series of tests on 23 glass fiber reinforced polymer (GFRP) confined concrete prisms. The primary variables in the investigation were the corner radius, layer of wrap, spacing of laterals and volume fraction of the polyolefin fibers. The test results demonstrated that the corner radius ratio is in direct proportion to the increase in the confined concrete strength. Furthermore, it is revealed and explained that the confinement provided by a jacket with sharp corners is insignificant in increasing the strength of the concrete prisms, but significant in increasing the ductility of the concrete prisms. A total of twenty three prisms of size 150 × 150 × 300 mm were tested under the strain control rate of loading.

The provision of adequate ductility in concrete structures is very important, in view of seismic resistance. The presence of micro-cracks even before loading the concrete at the transition zone and its internal progress in number, length, and size during loading, is responsible for the inherent weakness of concrete and results in poor ductility. This weakness can be rectified by the inclusion of fibers in the mix. The fibers help to transfer loads at the internal micro-cracks. In order to improve the strength and post-peak behaviour of hardened concrete for seismic resistance, fibers with high strength and elastic modulus with good dispersion properties are required. Traditionally, steel fibers are used for this purpose (Kaufmann et al 2007).

The inclusion of fibers delays the dilation of concrete by acting as crack arresters, and thus, helps indirectly in the confinement of concrete under compressive loads. Normal reinforced concrete may exhibit improved ductile characteristics due to direct and indirect confinement of concrete by lateral ties, FRP and fibers respectively. In the present investigation, the combined effect of the spacing of lateral ties, volume fraction of polyolefin fibers, varying corner radius and GFRP wraps, was studied from the point of view of the deformability characteristics of the FRPCFRC. A relation is proposed for the constitutive behaviour of the FRPCFRC under axial compression.

## EXPERIMENTAL PROGRAMME

**Scheme of the Experimental Work.** The experimental programme was designed to study the behaviour of FRP and lateral ties confined polyolefin fiber reinforced concrete (FRPCFRC) under axial compression, by testing prisms of the size of 150mm×150mm ×300 mm. The variables in the study are 0.7% and 0.9% volume fraction of polyolefin fibers, 145mm and 75mm spacing of lateral ties of 6mm diameter, corner radius of 5mm,15mm&25mm, and single and double layer of GFRP wraps. The programme consisted of casting and testing 23 prisms.

**Materials Used.** Polyolefin fibers (barchip macro structural synthetic fibers) of the length of 42mm, an equivalent diameter 0.79mm, aspect ratio of 53.2, continuously embossed surface texture, tensile strength of 550MPa, and Young's Modulus of 8.2 GPa were used. G.I. wire of 3.9 mm diameter was used as longitudinal holding bars. The lateral ties used were 6mm mild steel bars of 100mm×100mm. The lateral ties were 135$^{o}$ hooked at the ends. In the GFRP, glass fiber woven strand mat with polyester resin was used. The cement used was 53 grade ordinary portland cement conforming to IS specifications. The mix proportions adopted for the M30 concrete were 1:2.04:2.87, with a water cement ratio of 0.45 and a superplasticizer dosage of 0.6%.

**Casting of Specimen.** The ties were tied to the longitudinal bars at the required pitch in such a manner, that the hooks were distributed evenly on all the four corners. Figure 1 shows the mould and the reinforcement used for casting the prisms. Figure 2 shows the confinement effectiveness of corner radius. Figure 3 shows the prisms cast with different corner radii.

**Figure 1. Mould with corner radius and reinforcement cage**

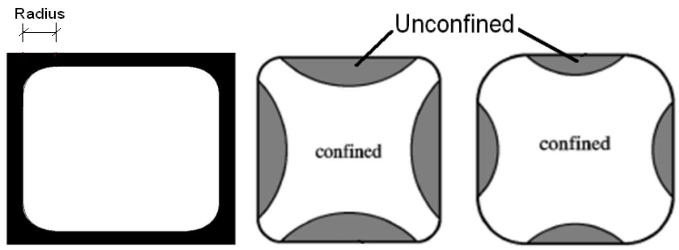


**Figure 2. Confinement effectiveness of corner radius**

**Figure 3. Views of GFRP wrapped prisms of different corner radii**

**Testing.** The cured specimens were capped with plaster of paris before testing to provide a smooth loading surface, to avoid any stress concentration during the application of load. A Tinius–Olsen servo closed loop controlled universal testing machine of 2000 kN capacity was used, for testing the prisms under axial compression. A compressometer suitable for prisms, which were fabricated by earlier investigators (Ramesh et al 2003) on confined concrete, was adopted. Figure 4 shows the schematic diagram of the compressometer. The prisms were tested under a strain rate control manner at the strain rate of $1\times 10^{-5}$ per second (0.18 mm/min).The test setup is as shown in Figure 5.

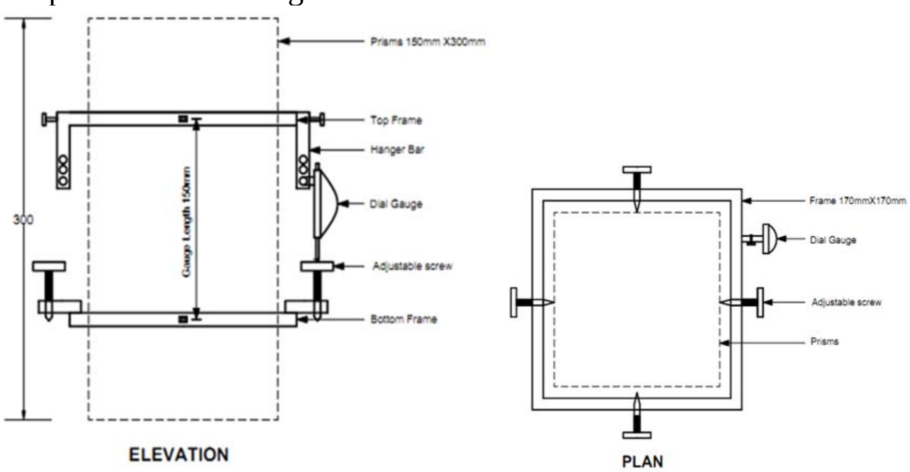


**Figure 4. Schematic diagram of** the **Compressometer**

**Figure 5. Test setup**

## RESULTS AND DISCUSSION

**Behaviour of the FRPCFRC.** In the case of the FRPCFRC specimens, the extent of the cracking and rate of decrease of the load after peak (in the descending portion of the stress–strain curve) depended upon the volume fraction of the fiber, and the spacing of ties confinement. The higher the volume fraction, the lower is the rate of decrease of the load, and the extent of spalling. This may be due to the improvement of the internal crack arresting mechanism, and the dimensional stability as well as the integrity of the material, caused by the presence of volume fraction of the fiber present in the concrete. Also, the presence of fibers might have enhanced the core concrete failure strain, and resulted in an improvement in the strength and ductility of the FRPCFRC.

**Stress–Strain Curves of the FRPCFRC.** The stress–strain curves were drawn by averaging the readings of each set. These strain curves show that the addition of the fiber has no significant influence on the stress–strain relationship up to 70–85% of the peak load of the control specimen. However, the influence of the fiber addition on the peak strength and ductility is highly appreciable. This may be due to the passive confinement of the core concrete, due to the improved interfacial bond stresses between the core and the cover concrete. This makes the cover and core concrete act as one unit in carrying the axial load and the resulting lateral strains. Such unification of the cover and the core concrete cannot be attained with the help of stirrups, even if they are employed in a more sophisticated configuration. Figures 6 shows a typical plot of the characteristic stress-strain values for two layer wrapped and closer spaced laterals for varied corner radii. A convenient way to quantify ductility is to use the toughness index and strain ductility factor. In this study, the strain ductility factor has been used to quantify ductility. The strain ductility factor is defined as the ratio of the failure strain of the FRPCFRC to the peak strain 0.002 of the plain concrete.

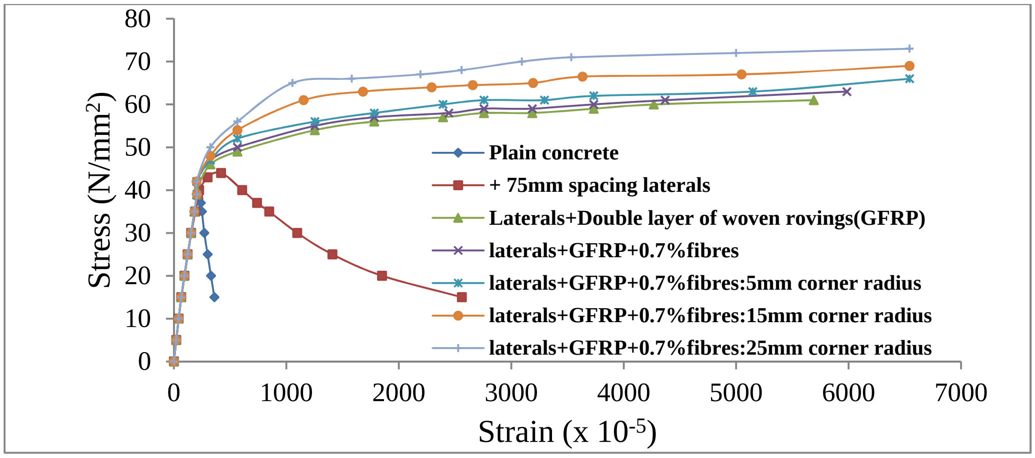


**Figure 6. Typical stress–strain curves of FRPCFRC prisms – Double Layer of GFRP and closer spacing of laterals**

## ANALYTICAL MODELLING

The Finite Element Method (FEM) is a powerful tool to effectively simulate the behaviour of the Fiber Reinforced confined concrete. The model was developed in ANSYS. These models show that when a proper numerical model is used, the Finite element models can effectively predict the behaviour of the FRPCFRC prisms. This analysis gives a better theoretical understanding, and helps in achieving an accurate confinement model. A finite element model of the FRPCFRC prism was developed and was validated by the experiment. The models were simulated using ANSYS 12.0 finite element software. Each program has its own arrangement, and specialized analytic procedures need to be properly incorporated in it.

A finite element model of the specimen was developed using the ANSYS 12.0 software package. The elements used in ANSYS to develop the model are the Solid65, Shell46 and Link8. The Solid65 element was used to model the concrete, the Link8 element was used to model the lateral ties and polyolefin fibers, and the shell 46 element was used to model the GFRP composite wrap. ANSYS provides a three-dimensional eight-noded solid isoparametric element, Solid 65, to model the concrete. This element has eight nodes with three degrees of freedom at each node-translation in the nodal *x*, *y* and *z*-directions. This element is capable of plastic deformation, cracking in three orthogonal directions and crushing. Depending upon the application, the Link8 element may be thought of as a truss element, a cable element, a link element, or a spring element, etc. The three-dimensional spar element is a uniaxial tension-compression element with three degrees of freedom at each node-translations in the nodal *x*, *y* and *z*-directions. The prisms were modeled in ANSYS software using the above said element types and material properties. Some of the modeled details are shown in Figures 7 to 9.

The results are in good agreement with the experimental values and the modeling of the various corner radii was found to be effective.

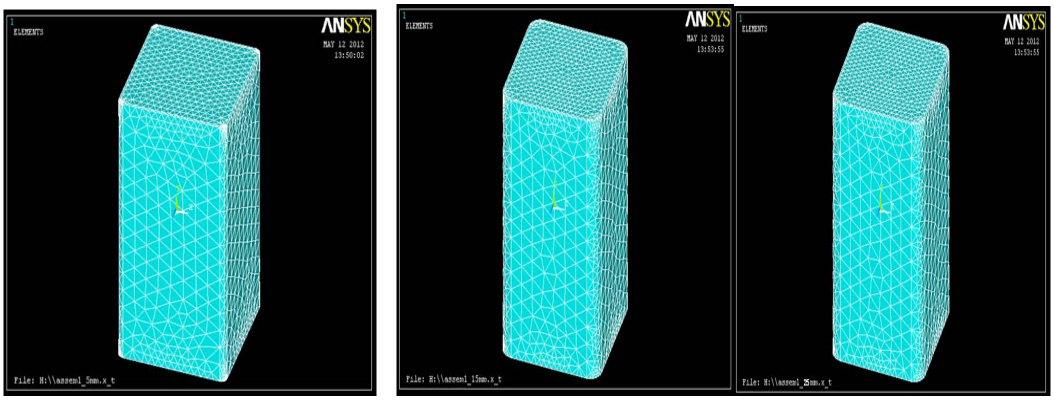


**Figure 7 Prism Models with sharp and rounded edges**

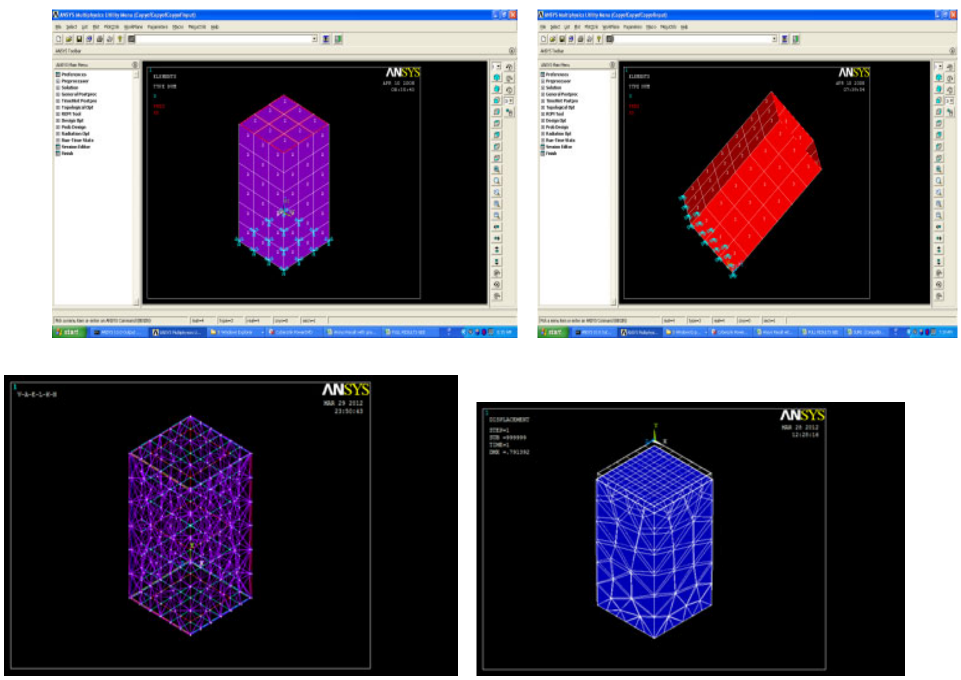


**Figure 8 Supports, loading and meshing for the FE model**

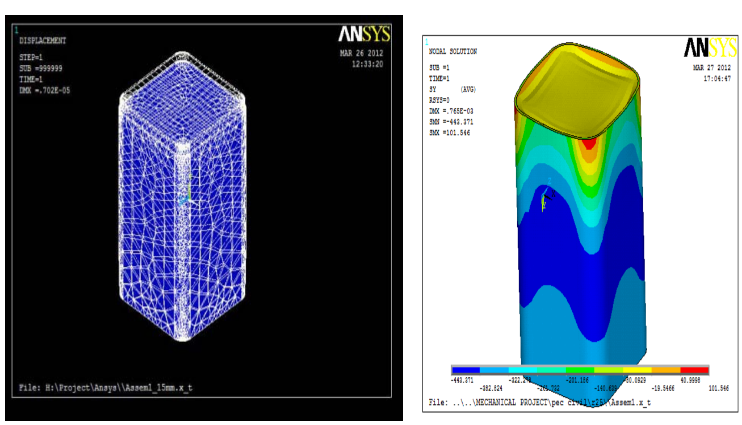

**Figure 9 Deformation shape and Von Mises stress diagram**

## CONCLUSIONS

The following conclusions can be drawn from the experimental and analytical investigations on the FRPCFRC with varied corner radii:

1. Polyolefin fiber addition to the lateral ties and GFRP confined specimens has an advantage over the confinement by lateral ties and GFRP wrap in improving the material properties, such as integrity, dimensional stability and performance under large deformations.
2. The provision of the GFRP wrap and fiber addition is an effective way of providing additional confinement of the concrete.
3. The FRP wrap and fiber addition resist lateral deformation due to load, and result in a confining stress to the concrete core, thereby delaying the rupture of concrete, and enhancing the ultimate compressive strength, the ultimate compressive stain, and failure strain of the concrete.
4. The smoothening of the edges of a square cross-section delays the rupture of the FRP composite at these edges, reduces the stress concentration, improves confinement action and avoids delamination of the wrap.
5. The stress-strain profiles proposed in this investigation can be used to predict the constitutive behaviour of the FRPCFRC in axial compression, with reasonable accuracy.

## REFERENCES


Riad Benzaid, Nasr-Eddine Chikh, Habib Mesbah "Behaviour of square concrete column confined with GFRP composite wrap," Journal of civil engineering and management, Jan.2008, pp. 115-120.

Domingo A. Moran and Chris P. Pantelides, "Stress-Strain Model for Fiber-Reinforced Polymer - Confined Concrete," Journal of composites for construction, Nov 2002, pp.233- 240.

J. Kaufmann et al.: Mechanical reinforcement of concrete with bi-component fibers Composites, Part A 38 (2007) 1975–1984

K. Ramesh et al.: Constitutive behaviour of confined fibre reinforced concrete under axial compression, Cement & Concrete Composites 25 (2003) 343–350

Ganesan N, Murthy J.: Strength and behaviour of confined steel fibre reinforced concrete columns, ACI Mater J 1990; 87(2):221–7.

M.N.S. Hadi: Using fibres to enhance the properties of concrete columns Construction and Building Materials, 21 (2007) 118–125

U. K. Sharma, P. Bhargava, and S. A. Sheikh: Tie-confined fibre-reinforced high-strength concrete short columns, Magazine of Concrete Research, 2007, 59, No. 10, Dec, pp. 757– 769.

M. A. Mansur, M. S. Chin and T. H. Wee: stress-strain relationship of high-strength fiber concrete in compression, journal of materials in civil engineering, Feb. 1999, pp 21-29

Al-Salloum, Yousef A. Influence of edge sharpness on the strength of square concrete columns confined with FRP composite laminates. Composites Part B: Engineering 2007; 38:640–650.

Lei-Ming Wang, Yu-Fei Wu. Effect of corner radius on the performance of CFRP-confined square concrete columns: Test. Journal of Structural Engineering 2008;30: 493–505.

Paula de, R.F. and Silva da, M.G. Sharp edge effects on FRP confinement of RC square columns. Journal of Engineering Structures 2002; 42: 703-712.