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ASSESSMENT OF CORNER RADIUS BY USING GLASS FIBER REINFORCED POLYMER IN CONCRETE

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ABSTRACT : This paper presents the experimental and analytical results of the study carried out to investigate the influence of the corner radius of the cross-section on the strength of small scale square concrete column specimens confined with glass fiber reinforced polymer (GFRP) composite laminates. The experimental part of the study was achieved by testing 48 specimens under uniaxial compression.

Depending on the selected radius of the edges. The sharpest square specimens had a corner radius of 5mm, 15mm, and 25mm to make composite application easier and to avoid a premature rupture of the composite. The result show that smoothening the edges of square cross-section plays a significant role in delaying the rupture of FRP composite at these edges, and the efficiency of FRP confinement is directly related to the radius of cross-section edges. A modified analytical model is presented to predict the strength of FRP-confined square sections. The predicted results are found to be in excellent agreement with the measured ones.

INTRODUCTION

In recent years, many have proposed their evaluation in infrastructure .and most of the infrastructures have reached a serious state of degradation and are, thus, in need of repair. Axial strength and ductility increase of concrete columns is needed whenever repair and strengthening are involved. Repair may be required when columns are damaged under excessive external loads or due to erosion in exposed environments. Strengthening may be required when there is a change of structural use or removal of some adjacent load bearing structural members. In such cases, the required additional load bearing capacity of the existing columns can be provided by external confinements. Lateral confinement has been known to add both strength and ductility in the axial direction for concrete columns and this idea was originally developed back in the 1920s' (Richart et al. 1927, 1928).

Because the total cost of replacement of the deteriorated structures is so overwhelming, the development of innovative rehabilitation and strengthening techniques is requested to extend the life expectancy of many existing structures. Some of the new methods that are being considered, and which are most promising, make use of composite materials. One strengthening technique currently being studied is the confinement of concrete columns with composite materials.Lateral confinements for concrete columns can be in various forms. They appear chronologically as (1) spiral and circular reinforcements; (2) concrete jacketing; (3) steel jacketing; and (4) fiber reinforced plastic (FRP) composite jacketing. Steel has been a conventional and widely used construction material.

Concrete is a one of the material without decay until insert steel. However, corrosion is one of the largest drawbacks of such material. Weight can be another problem because the construction costs can surge when the installation is labour intensive. Concrete jacketing, though has a lower cost, simply adds weight and cross sectional area to the original structure and may be undesirable.

On the contrary, FRP composites, initially developed for aerospace and automobile applications, are found to be a very promising material for civil engineering applications because of their high strength/weight ratio, high corrosion resistance, ease of installation, and relatively low cost of maintenance.

In view of these many advantages, research has been in progress in the past two decades. Experimental investigation and analytical model development are being performed in parallel. Small-scale testing has been the focus of most experimentation programs, although a limited number of large-scale testing has taken place. Analytical models have been proposed base on the basic form suggested in earlier research on spiral reinforcement confinements (Richart et al. 1927, 1928). Concrete columns confined with the fiber reinforced polymer (FRP) become increasingly popular for the repair and retrofitting of concrete structures. The popularity of FRP composites is due to their well-known advantages, including a high strength-to-weight ratio and excellent corrosion resistance. One important application of FRP composites is as a confining material for the retrofitting of existing reinforced concrete (RC) columns with FRP jackets. Carbon fibers have been used successfully for more than 10 years to retrofit structures such as building columns, bridge or expressway piers, and chimneys.

For local effects, fiber responses were also not addressed fully. Most researches utilized the fibers in the hoop direction, aiming at producing the maximum confinement effect. However, the possibility of using fibers in different orientations to improve the failure modes and to promote safety should also be considered. Catastrophic failures have been reported unanimously. The roles of fibers in different orientation have not been investigated and pointed out. The effect of unbalanced overlap design layout was not addressed. Local end condition, which may be correlated to the real world wrapping practice at column ends, needs to be addressed. Designs of strengthening systems in the field mainly rely on the previously developed models that were originally based on steel jacketing and spiral or circular reinforcements. For manufacturing effects, the effects of composite laminate stack-up sequence need to be adequately studied and reported.Also, initial imperfections such as air pockets and fabric wrinkling, which can be crucial to the overall structural responses, need to be studied.

An overview of frp composite materials

FRP composites are defined as the materials that consist of high strength/stiffness fiber reinforcements embedded in a resin matrix material. Engineering properties of composites, in most cases, are dominated by fiber reinforcements. More fibers usually give rise to higher strengths. However, low matrix/fiber ratio may lead to strength reduction or premature failure. Fiber lengths and orientations can also affect the properties considerably.

Resin matrix is an adhesive that supports the fibers from buckling under compression, binds the fibers together through cohesion and adhesion, protects the fibers from attack and micro-cracking during service, and provides shearing strengths between fabric layers. The shearing strengths result in resistances to delamination, lap joint debonding and impact damage. Choice of the particular types of fibers and resins depends on the specific applications. Strength requirement, service life, environmental conditions, and cost are the issues that need to be considered. For example, the choice of composite materials for the retrofit of a group of offshore pier columns would be very different from the strengthening of a group of interior building columns. Load bearing strength, level of exposure, service life, fire and water resistances, ease of installation, and project cost are the major issues that require thorough considerations.

Use of FRP composites in column retrofit and strengthening are mostly in the form of continuous fiber strands and weaved fabric cloths. Fiber strands are used in the process of filament winding using an automated system, a technique that produces column confinement with slight fiber pretensioning. Weaved fabric cloths are wrapped on column surfaces directly using various techniques such as wet lay-up and vacuum bagging. The confinement becomes effective after the fabric cloths are fully cured and hardened.

Table :1 Comparison of inherent properties of fibers

	Specific gravity	Tensile strength		Tensile modulus	
		MPa	10^3 Psi	GPa	10^6Psi
E-glass	2.58	2689	390	72.4	10.5
S-2-glass	2.48	4280	620	86.0	13.0
ECR-Glass	2.62	3625	525	72.5	10.5
K-49 Aramid	1.44	3620	525	131.0	19.0
AS4 Carbon	1.80	3790	550	234.0	34.0

Table :2 Compositional ranges for commercial glass fibers

	E-glass range	S-glass range	C-glass range
Silicon dioxide	52-56	65	64-68
Aluminium oxide	12-16	25	3-5
Boric oxide	5-10	_	4-6
Sodium oxide and potassium oxide	0-2	_	7-10
Magnesium oxide	0-5	10	2-4
Calcium oxide	16-25	_	11-25
Barium oxide	_	_	0-1
Zinc oxide	_	_	_
Titanium oxide	0-1.5	_	_
Zirconium oxide	_	_	_
Iron oxide	0-0.8	_	0-0.8
Iron	0-1	_	_

Hardeners for epoxies: Epoxy resins can be cured at different temperatures ranging from room temperature to elevated temperatures as high as 347 F (175 C). Post curing is usually done. Epoxy polymer matrix resins are approximately twice as expensive as polyester matrix materials. Compared to polyester resins, epoxy resins provide the following general performance characteristics:

A range of mechanical and physical properties can be obtained due to the diversity of input materials

No volatile monomers are emitted during curing and processing

Low shrinkage during cure

Excellent resistance to chemicals and solvents

Good adhesion to a number of fillers, fibers, and substrates

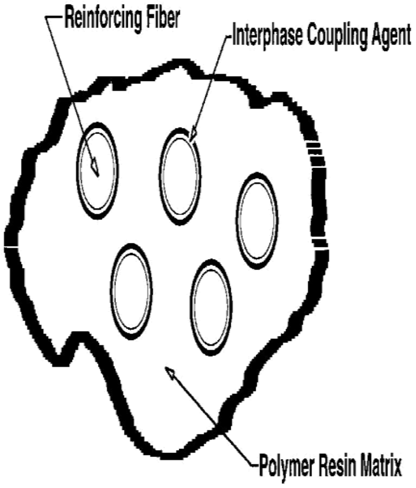

Fig: 1 Composite structure at the micro -mechanical lev

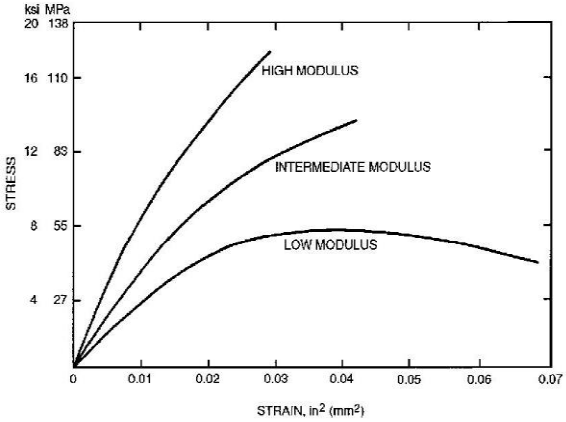

Fig: 2 Stress-strain diagram for three epoxy materials

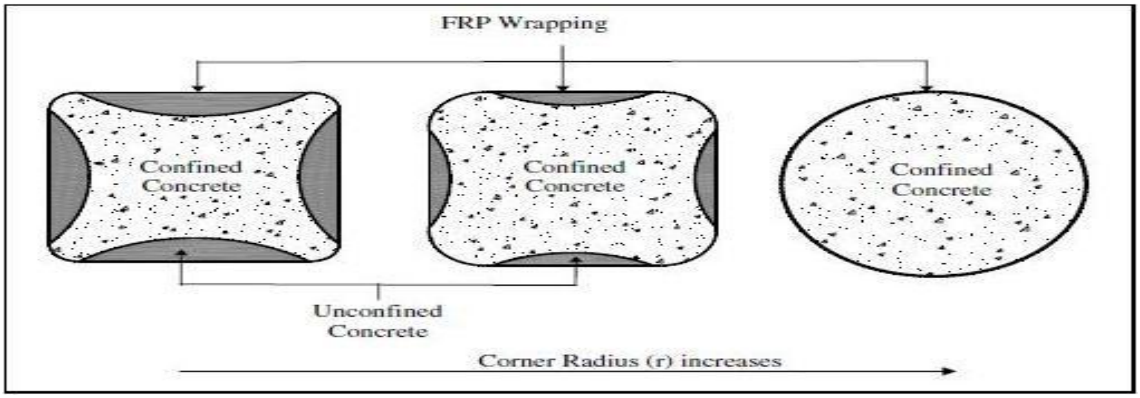

Fig: 3 Effect of corner radius on confined concrete in square and cylindrical columns

FAILURE MODES

The results presented by showed that all of the columns failed when the confinement wrapping ruptured. For carbon-wrapped specimens, there was insignificant delamination between the adjacent plies observed at failure. The breakage line was generally clean and perpendicular to the fibers. On a few occasions, a very slight slip between the two external plies of the specimens occurred. In almost all of the cases, and for whatever corner radius, the breakage line appeared at a corner, exactly at the end of the rounding

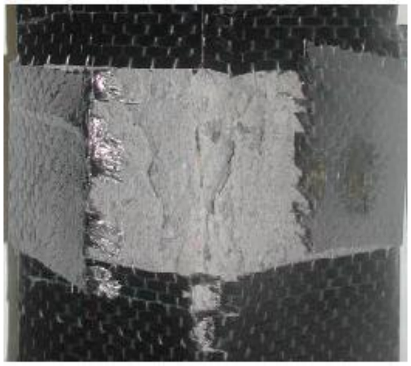

Fig: 4 Failure mode of CFRP Prismatic specimens

Fig: 5 Failure mode of CFRP confined Cylinders specimens confin

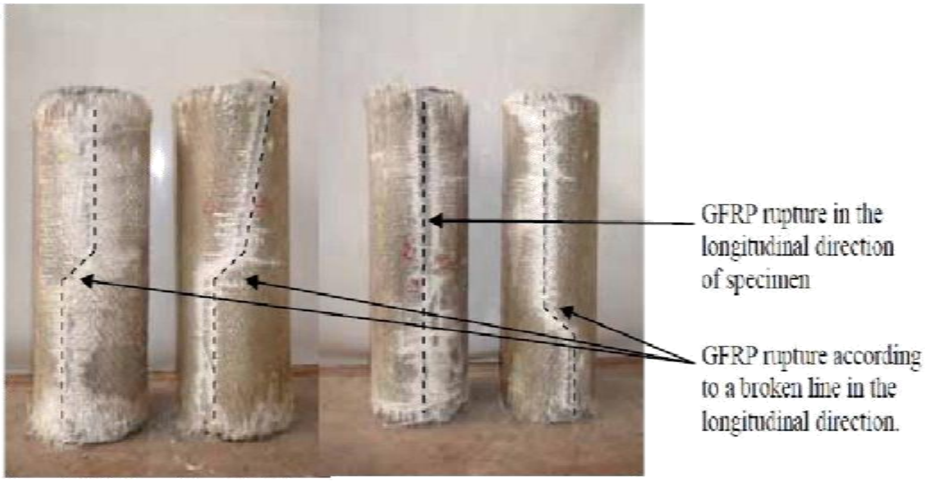

Fig: 6 Failure mode of GFRP confined Prismatic specimens

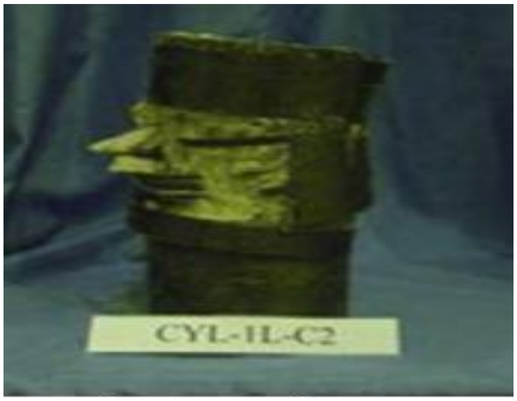

Fig: 7 Failure mode of GFRP confined Cylinders specimen

RESULTS AND DISCUSSION

In this chapter the discussion for failure mode and stress strain characteristics of confined concrete with external wrapping has studied in addition to plain and reinforced concrete prisms and ultimate load corresponding to strain are given in this chapter.

Glass fiber wrapped specimens typically failed by a fracture of GFRP composite at or near the corner of the specimens due to the stress concentration in those regions. Approaching failure load, the appearance of white patches was found, which indicated the yielding of E-glass and resin. In all cases, the specimen failure was the result of the rupture of the FRP jacket. Clicking sounds could be heard during the loading stage, and failure occurred suddenly with an explosive sound. For most wrapped specimen, it was associated with concrete crushing at or near the column ends and marked by wraps rupturing in the circumferential direction. After failure, disintegrated concrete was found.

Failure of GFRP wraps was observed at or near a corner in all the specimens mainly due to stress concentrations. Failure modes of specimens are shown in Figure 8 and Figure 9

Results show a significant improvement of load carrying capacity and failure strain with the increase of corner radius and confinement level. Stress–strain curves, which characterize the confined concrete, are bilinear whatever the strength of the concrete core. This study reveals a significant change of behaviour when the concrete is confined. The tests proved that the benefits of confinement could be enhanced by corner radius, which can be seen from the results of testing the repetitive compressive loading prisms.

The stresses and strains are no longer uniform throughout the cross section of the specimen. Therefore, Table 4.1 presents the average values of stress and strain along with the maximum and minimum stresses calculated based on the assumption of linear variation of strain across the section. The axial strain was measured at the mid-height of the specimens. The average ultimatestrengths of the specimens decreased substantially due to the load.

Fig: 8 Failure mode of GFRP concrete prisms

Fig: 9 Tested specimen

Table: 3 Stress-Strain Response of Prisms

Type of Specimen		Ultimate stress (N/mm^2)	Number of Cycles	Failure Strain
Without laterals and without Wrapping	CS (Zero Corner radius)	31.35	1	0.003
	C1 (5mm Corner radius)	32.13	1	0.0032
	C2 (15mm Corner radius)	33.21	1	0.0038
	C3 (25mm Corner radius)	32.65	1	0.0041
Without laterals and with Wrapping	WCS (Zero Corner radius)	32.12	2	0.0076
	WC1 (5mm Corner radius)	35.84	3	0.0184
	WC2 (15mm Corner radius)	38.42	4	0.0202
	WC3 (25mm Corner radius)	40.25	5	0.028
150 mm c/c lateral Spacings with Wrapping	WTCS (Zero Corner radius)	33.23	3	0.014
	WTC1 (5mm Corner radius)	38.36	6	0.022
	WTC2 (15mm Corner radius)	43.23	7	0.027
	WTC3 (25mm Corner radius)	45.03	8	0.038
75 mm c/c lateral Spacings with Wrapping	WLCS (Zero Corner radius)	35.01	4	0.021
	WLC1 (5mm Corner radius)	39.45	7	0.030
	WLC2 (15mm Corner radius)	45.72	8	0.037
	WLC3 (25mm Corner radius)	47.35	9	0.042

Tables 3 show the summary of the experimental results obtained for all unconfined and confined test specimens. These tables clearly show the gain in strength and strain achieved through confinement of columns. Further, these tables also illustrate that as corner radius increases, gain also increases and it becomes maximum. For unconfined specimens, at relatively lower axial strains, strains in the lateral direction reaches to tensile strength of the concrete. However, for confined specimens there is an FRP laminate to take this lateral tension which makes specimen to carry a much higher value of axial strain. The confined specimen fails if lateral strains reach to such a high value that fiber fractures or concrete crushes.

Table 4.2 Summary of experimental results Prisms.

Prism	Ultimate Stress(MP)	Failure Strain	% increase in Ultimate Stress	Increase in Strain (times)
CS	31.35	0.003	-	-
C1	32.13	0.0032	2.49	1.07
C2	33.21	0.0038	5.93	1.27
C3	32.65	0.0041	4.15	1.37
WCS	33.12	0.0076	2.46	2.53
WC1	35.84	0.0184	14.32	6.13
WC2	38.42	0.0202	22.55	6.73
WC3	40.25	0.028	28.39	9.33
WTCS	33.23	0.014	6.00	4.67
WTC1	38.36	0.022	22.36	7.33
WTC2	43.23	0.027	37.89	9.00
WTC3	45.03	0.038	43.64	12.67
WLCS	35.01	0.021	11.67	7.00
WLC1	39.45	0.03	25.84	10.00
WLC2	45.72	0.037	45.84	12.33
WLC3	47.35	0.042	51.04	14.00

EFFECT OF CORNER RADIUS

Figure 10 and 11 illustrates graphically how as the corner radius increases, gain in strengthand axial strain due to confinement increases

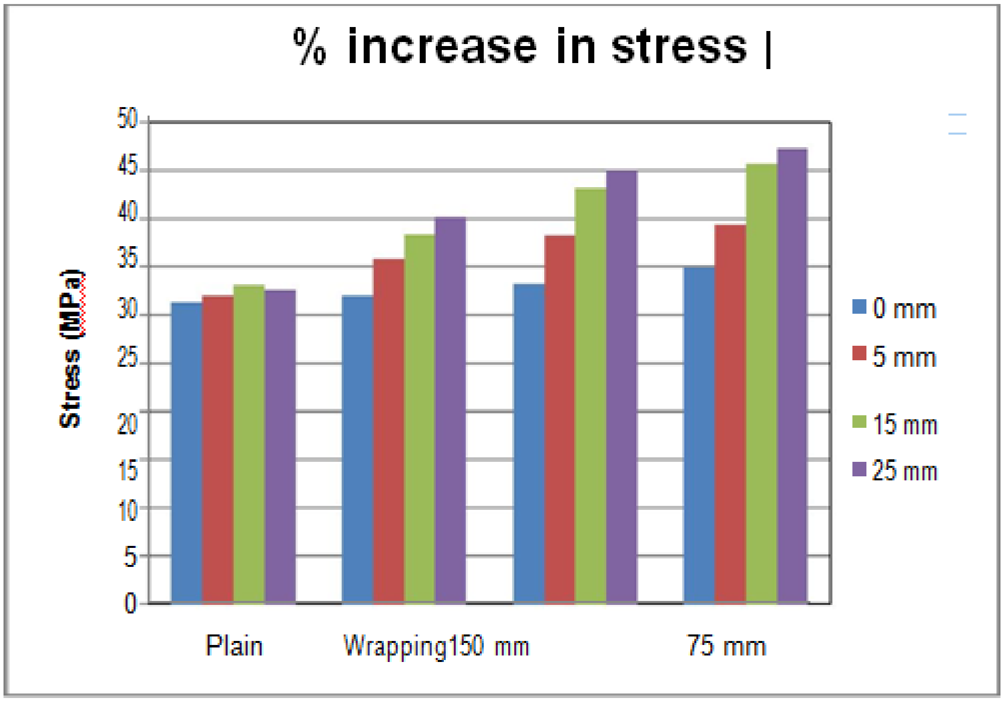

Fig. 4.23 Effect of corner radius for stress

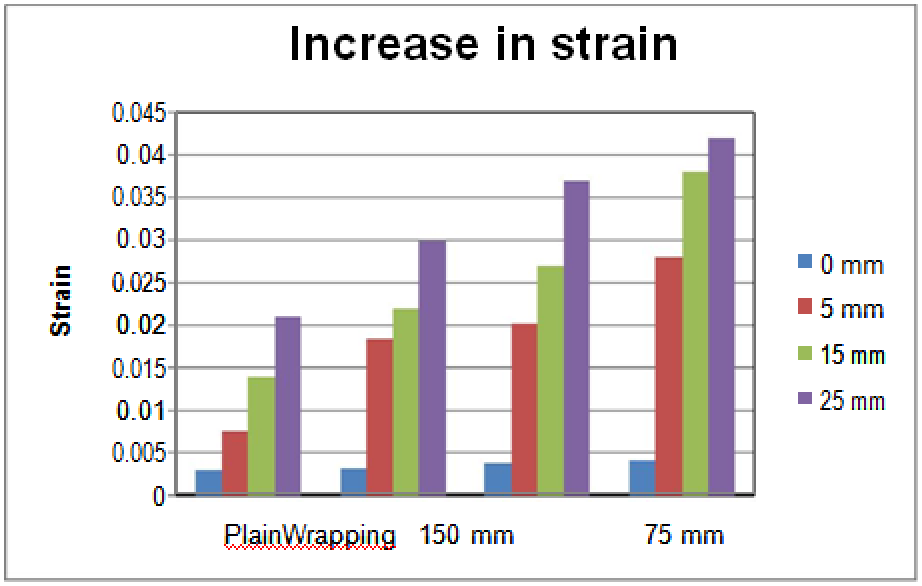

Fig. 4.24 Effect of corner radius for strain

CONCLUSION

Based on the investigations of both experiments and numerical analyses, the following conclusions can be reached:

- The provision of FRP is an effective way of providing additional confinement of concrete.
- The strength of confined prisms is higher for larger corner radius than it is for sharp edge.
- The failure of the square prisms always starts at one of the corners due to stress concentration at corner the confinement pressure can be reduced in sharp edge.
- To expand the strong constraint zone & diminish the stress concentration the sharp edge can be done rounded corners.
- Square column with rounded corners is to improve the effectiveness of FRP confinement
- The FRP resists lateral deformation due to load and results in a confining stress to the concrete core thereby delaying the rupture of concrete and enhancing both the ultimate compressive strength and the ultimate compressive stain of the concrete.

7.The maximum stress increased by prism with 25mm corner radius single layer GFRP confined with 75mm c/c laterals failure strain and 51.04% as compared with control specimen.

i. The maximum failure strain was increased by prism with 25mm corner radius single layer GFRP confined with 75mm c/c laterals 14 times when compared to control specimen.

ii. The external confinement with Glass Fibre reinforced polymer (GFRP) composites can significantly increase the strength of the specimen under repetitive compressive loading. From the experimental results,

iii. Bending affects the performance and efficiency of the FRP laminate, and the corresponding confinement action depends on the curvature of the corners, therefore corner radius increases the ductility of the concrete specimen.

iv. Radial stress on FRP laminate relates with corner radius in a different way, it decreases with increasing corner radius.

v. The failure of the square columns always starts at one of the corners proving that the stress concentration occurs at the corners .

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