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Experimental Investigations on the Glass Fabrics for Confinement of Concrete Specimens

Smitha Gopinath[1,2], A. Ramachandra Murthy[1] and Nagesh R. Iyer[1]

Abstract: This paper deals with the performance of concrete specimens confined with different glass fabric reinforcement in organic binder consisting of resins. Three varieties of glass fabrics such as woven roving (WR), chopped strand mat (CSM), and textile reinforcement have been studied in the investigation. Experiments have been conducted on unconfined and confined concrete cylindrical specimens under compression. The effect of number of layers on confinement has been studied for specific cases. Specimens have been tested under displacement control. It is observed from the experiments that there is an increase in load carrying capacity as well as energy absorption capacity for specimens confined with different glass fabrics, and these materials can be used for retrofitting applications. It is observed that, in the case of specimens confined with textile reinforcement, failure is less abrupt compared to WR and CSM. The experimental findings will help the designer to choose the appropriate material towards confinement for practical applications.

Keywords: Confined Concrete, Glass Fabrics, Woven Roving, Chopped strand mat, Textile reinforcement.

1 Introduction

Reinforced concrete (RC) structures which are built only for gravity loads show poor performance during earthquakes. Concerns about the seismic response of existing structures grew considerably and poses significant challenge to manage the seismic risk by identifying a suitable strengthening material capable of enhancing the shear strength and ductility. Selecting new materials for strengthening RC structures requires proper understanding of the material behavior. The use of fiber reinforced polymers (FRP) in strengthening and seismic retrofitting has gained popularity among structural engineers due to numerous attractive features of these ma-

[1] CSIR-Structural Engineering Research Centre, CSIR Campus, Chennai 600 113, India
[2] Corresponding Author: smithag@serc.res.in, smithagopinath13@yahoo.com

terials, such as high specific strength, corrosion resistance, ease and speed of application at minimal change of cross section etc. Despite its advantages over other methods, the FRP strengthening technique is not entirely problem free (Engindeniz et al. 2005; Coronado and Lopez, 2007). It is dependent on the bonding area of concrete, tensile capacity of concrete and the type of surface preparation used. Further, the organic resins used to bind and impregnate the fibers entail a number of drawbacks, namely poor behaviour at temperatures above the glass transition temperature, relatively high cost resins; potential hazards for the manual worker, non-applicability on wet surfaces or at low temperatures, lack of vapour permeability and incompatibility of resins and substrate materials.

After the earlier attempts by Kurt (1978) and Fardis & Khalili (1981, 1982), a large amount of experiments were performed to investigate the behavior of concrete columns confined with FRP spirals (Ahmad et al. 1991; Nanni and Bradford 1995), wraps (Harmon and Slattery 1992; Picher et al. 1996; Watanabe et al. 1997; Miyauchi et al. 1997; Toutanji 1999; Matthys et al. 1999; Rochette and Labossie're 2000; Micelli et al. 2001; Rousakis 2001), and tubes (Saa? et al. 1999; La Tegola and Manni 1999; Fam and Rizkalla 2000). Experimental studies were conducted on FRP confined concrete cylinders to find out the enhancement in strength and ductility by Gu and Zuo (2006), Wu et al. (2007). Experimental investigation were made on the response of chopped strand mat glass fibre laminates to blast loading by Franz et al (2002) and results were found to be very encouraging. An investigation was made on worn surfaces of chopped glass fibre-reinforced by Tayeb et al (2008). Ye et al. (1998) tested a concrete column of 300 mm height and 150 mm diameter for confinement effect of E-glass woven roving (WR), combined with chopped strand mat (CSM) and glass fiber tape (GFT). A vinyl-ester resin was used to restrain concrete columns using a wrapping procedure with different architectures. The study concluded that, use of E-glass fibers and the vinyl-ester resin to reinforce concrete columns externally is effective, with a low raw materials cost. Reinforcing efficiency depends greatly on the composite architecture, with a hybrid system of roving cloth, chopped strand mat, and glass fiber tape showing highest level of enhancement. Wrapping deteriorated or damaged concrete columns with WR/CSM glass fiber composite jackets can be an effective way to restore the load-carrying capacity and to greatly increase the structural integrity. Xiao and Wu (2000) and Lam and Teng (2003) tested concrete cylinders wrapped with FRP composites. The strength of FRP confined concrete was increased compared to the unconfined concrete depending on the type and amount of FRP composite. From the literature, it is observed that the experimental studies on different glass fabrics are limited. Further, the information on a relative comparison of confinement effect of different fabrics with same binding matrix is scanty.

In the present work, three different types of glass fabrics are used to investigate the confinement effects for concrete specimens. The present paper focuses on the use of woven roving, chopped strand mat and an alkali resistant glass fabric or so called textile reinforcement for confinement effect. The binders used to embed these glass fabrics are organic resins. Unconfined as well as confined concrete cylindrical specimens are tested under uniaxial compression. The enhancement in strength, ductility and energy absorption capacity has been studied in detail. Further, the failure patterns of three strengthening systems are investigated and discussed.

2 Experimental Details

The experimental program is executed with three main purposes: 1) to explore different types of fabric architecture for confinement effect 2) to assess constructability of the different strengthening systems and 3) to evaluate effectiveness of different strengthening systems by testing confined concrete cylinders in compression.

2.1 Specimen fabrication

The concrete cylinder of diameter 150mm and height 300mm are used for unconfined and confined specimens. The mix for concrete cylinder was designed according to Indian standard IS:10262-1982 for M30 grade concrete and obtained as 1:1.27:2.78 with water cement ratio 0.45.

2.1.1 Binding material for confining system–Organic Resin

The resin used is thixotropic accelerated and has a viscocity that ensures glass fibre impregnation. It is easy to mix and can be applied by brush. Mixing procedure for organic binder for wrapping with glass fabric is given below.

1. Resin mixture is prepared by mixing resin, accelerator and catalyst. The sequence of mixing is as follows

Resin + Accelerator = Premix

2. Accelerator (cobalt octoate - violet colour liquid) is added 1.5 to 2% of resin.

3. Premix is prepared in quantities as required for the whole cating process.

4. Catalyst is added 1.5 to 2% of resin to the premix in small batches depending on the pace of moulding activities and used it before gelation. Normally gelling will start 15 to 20 minutes after mixing of catalyst.

5. Fillers like chalk powder is added to resin before premix preparation.

The physical and mechanical properties of applied resins are given in Table 1.

Table 1: Physical and mechanical properties of resin

Polymer	Tensile strength (MPa)	Elongation (%)	Density (g/cm^3)	Heat Distorsion Temperature
Polylite	72	4.5	1.2	85^{0}C

2.2 *Fabric Architecture*

2.2.1 Woven roving

One type of glass fabric used in the present investigation is bi-directional woven roving glass fabric with $0^o/90^o$ orientation (Fig. 1). Typical properties of WR are as follows (Table 2& Table 3):

Table 2: Properties of the fabric

Fabric name	Density (No. of Ends/cm)		Area Weight g/m^2	Weave	Moisture Content (%)	Combustible Content (%)
	Warp	Weft	ISO 3374		ISO 3344	ISO 1887
EWR360	3.20	1.80	354 ± 18	Plain	$\leq$ 0.15	$0.40 \sim 0.80$

Table 3: Mechanical Properties of the fabric

Typical Properties	E-Glass
Density (g/cm^3)	2.60
Young's Modulus (GPa)	73
Tensile Strength (GPa)	3.4
Tensile Elongation (%)	2.4

The plain weaved fabric is comprised of fibers in two perpendicular directions with slightly different density (in terms of ends / cm) in both directions.

2.2.2 Chopped strand mat

Another type of fiber reinforced polymer material selected in the investigation is chopped strand mat (CSM) for confining of concrete. Continuous fiber-reinforced CSM with polymer matrix is considered as a composite, heterogeneous and anisotropic material with liner elastic behavior up to failure.

The CSM shown in Fig. 2 is made from fibre glass strands of 50mm length, which are evenly dispersed and bonded together with the emulsion binder. The emulsion

Figure 1: Woven Roving E-Glass Fabric

Figure 2: Chopped Strand Mat (CSM)

binder used is PolyVinylAcetate (PVAc). The mechanical properties of CSM are given in Table 4.

Table 4: Mechanical properties of the Chopped Strand Mat

Property	Values
Tensile strength (MPa)	108
Tensile Elongation (%)	1.8
Tensile Modulus (MPa)	7800
Flexural Modulus (MPa)	6770
Flexural Strength (MPa)	204
Flexural Elongation (%)	3.4

2.2.3 Textile reinforcement

An alkali resistant mesh/fabric type of reinforcement (Fig. 3) characterized by a mean tensile strength of 45kN/m in wrap and weft direction is selected. The mesh size of the fabric is 25mmx25mm. The mechanical properties of textile reinforcement are given in Table 5.

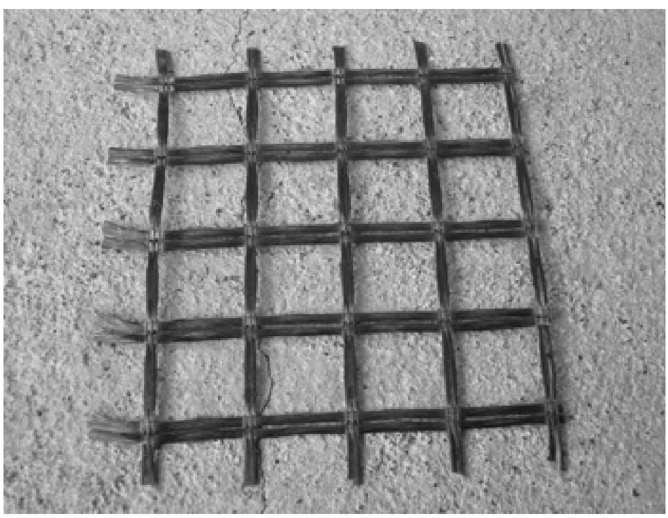

Figure 3: Architecture of glass fabric

Table 5: Details of glass fabric

Fabric name	Coated with	Elongational break (max)	(weight) mass/unit area (g/m^2)	Roll length	Roll width	Grid size	Tensile strength
SRG-45	Modified acrylic polymer	<3%	225	45.7m	0.91m	25mm x 25mm	45kN/m (Across width)
							45kN/m (Across length)

2.3 Specimen preparation

The proper adhesion of the fabric is very important in order to ensure proper strengthening. For this, surface preparation is done prior to applying a coat of resin. The outer surface of the concrete cylinders is ground by grinders such that very minor change in the dimension occurs. Fig. 4 shows the specimen with surface prepared. After surface preparation, 1^{st} layer of resin is applied and then the fabric is wrapped on the cylinder and again a second layer of resin is applied. This ensures thorough impregnation of the fabric and proper adhesion with the surface of the concrete specimen. The wrapped specimens are allowed to dry for a period of 24hrs during which proper bond strength is gained.

2.4 Test Details

The specimens are tested under servo controlled UTM machine of 2500kN capacity. Before the testing, the specimens were checked dimensionally and a detailed visual inspection was made and all information was carefully recorded. Sulphur capping has been done to ensure the uniform load transfer to the specimen. In each specimen, two LVDT's have been fixed and connected to data acquisition system to measure axial deformation. After setting both the LVDTs, slowly the loading frame has been given displacements and the equivalent load and deflections have been recorded simultaneously. The tests have been conducted according to the American Society of Testing and Method (ASTM) standards for all the specimens under uniaxial compression with displacement controlled loading. The details of tests are elaborated below.

Figure 4: Specimen with its surface prepared

2.4.1 Unconfined Specimen

The maximum strength for the control cylinder (unconfined) tested in displacement control mode was 38.4 MPa. Typical failure of control cylinder is observed to be cone and lateral shear. A control cylinder after testing can be seen in Fig. 5.1 for cone failure & 5.2 for lateral shear failure.

Compressive stress values for the cylinder is calculated based on the area of the concrete cylinder and the axial strain is calculated as the average change in the length over the original length of the cylinders. The stain corresponding to the peak stress value for the plain specimen is 0.0027 mm/mm. From the post peak behavior, it can be noted that after the specimen fails no appreciable strength is left in the structure. Beyond a strain value of 0.004, a sharp decrease in strength is observed. Fig. 6 represents the stress-strain behavior of the control cylindrical specimen derived using the load and displacement data obtained from the test.

2.4.2 Specimens confined with woven roving

Six cylinders wrapped with woven roving are tested in displacement control mode in order to capture the post peak behavior of the specimen (Smitha et al., 2012).The loading rate is 0.2mm/min till the strain value in the specimen reached 0.0015 and

Figure 5: 1) Control specimen (Lateral Shear); 2) Control specimen (Cone Failure)

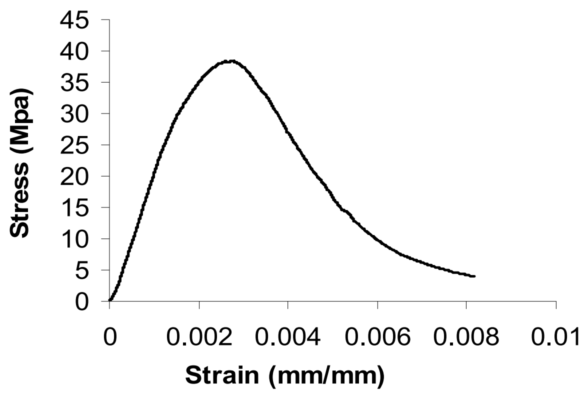

Figure 6: Stress vs. strain for control specimen

thereafter the rate is 0.02mm/min. Specimens wrapped with single layer woven roving and double layer woven roving are studied.

2.4.2.1 Specimen wrapped with 1Layer of WR

All the four single layered specimens (WR-1, WR-2, WR-3, WR-4) were tested under similar setup and the behavior of each specimen was individually recorded. The stress strain curve of each specimen is obtained in the same way as for the control specimen. The post peak behavior for all wrapped cylinders is observed to be different than that of the control specimen. Wrapped cylinders failed at higher peak loads and undergone larger displacements than the control cylinders. This is especially evident in Fig. 7, where stress vs. strain curves from both control and wrapped specimens are plotted by normalizing with respect to the control specimen.

The energy absorbed by the structural member play a very important role in enhancing its life under any kind of load, especially seismic loads. The greater the energy absorbed, the greater is the duration for which a structural member can sustain a given type of load. The area under any stress-strain curve gives an idea of the energy absorbed by the specimen during loading. Hence, the area under the stress-strain curve of each sample was analyzed and compared with the control specimen to understand the effect of wrapping under loading. The area under the stress-strain curve of the WR-1 cylinder specimen is approximately 1.5 times larger than the area of the control cylinder (Table 6). Samples WR-2 and WR-4 had approximately 10% more area than WR-1 and WR-3.

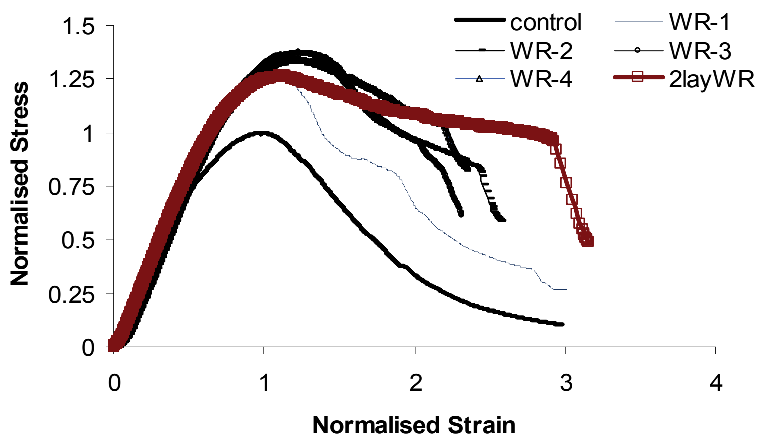

Figure 7: Normalized Stress Strain plot

2.4.2.2 Two Layer woven roving

The 2 Layer wrapped specimen showed highly enhanced ductile property when compared to the single WR confined specimen. As evident in Fig. 4, the 2LayerWR specimen has the maximum energy absorption capacity, approximately 2 times the control specimen and 30% more than that of the single layer WR specimen (Table 6).

Owing to the increased energy absorption the failure in each of the wrapped sample is observed to be largely brittle with sudden rupture of the fabric, however minor change in modes of failure is observed in each case.

2.4.2.3 Modes of Failure

For all the specimens wrapped with WR, the high energy absorption resulted in sudden failure due to sudden release of the absorbed energy. Minor changes in

Table 6: Area under the curve for different specimens

Specimen	Control	WR-1	WR-2	WR-3	WR-4	WR (avg)	2LayWR
Area Under Curve (wrt to control specimen)	1	1.45	1.61	1.49	1.57	1.53	2.04

the failure modes were observed for different specimens with respect to control. The failure of each specimen is discussed here under. For WR-1 Tensile rupture of fabric is observed in this specimen. The fabric is splitted along the length of the cylinder (Fig. 8(a)). The crack in the fabric initiated from the centre and propagated along the length. 45% more energy absorption is observed in this sample. The post peak softening is not appreciable because of debonding of the fabric from the concrete surface. However, an increase in strength is observed; the sample is failed at a peak stress of 48 MPa, i.e. 1.26 times the control specimen, the failure is sudden and almost vertical drop in the stress strain curve of the sample as shown in Fig. 7.

In the case of WR-2, The failure in this case is also sudden occurred at a strain of 0.0067(mm/mm) with huge sounds indicating the breaking of the fabric. The specimen failed at a peak stress of 52.88 MPa. This sample showed the highest increase in strength compared to other single layer wrapped samples. The white patches indicated the debonding between the fabric and the concrete surface noticed first after a strain value of 0.0045(mm/mm) as a result of which appreciable post peak is observed in the specimen as shown in Fig. 4. Hence as expected, this specimen absorbed the maximum amount of energy amongst all other single layer wrapped specimens. The area under the curve for this sample is 60% more than the control specimen. At the strain of 0.0067(mm/mm), a sudden drop in the curve can be seen in Fig. 8(b), this is the point where the specimen is completely collapsed and the stiffness has drastically reduced.

For WR-3, The mode of failure was almost similar to that of the WR-1 sample, but the WR-3 sample absorbed greater amount of energy and had a peak stress value higher than WR-1. The peak stress value attained by the WR-3 sample is 52.7 MPa and the strain corresponding to this stress value is 0.00332, nearly as much as that of WR-2 at peak stress. The ductile behavior of this sample was also considerably enhanced. The energy absorbed by the sample is 0.49 times the plain sample and the end failure is due to the rupture of the fabric. The debonding between fabric and concrete was considerably less compared to other samples, as is visible from the Fig. 8(c), this could a possible explanation for the post peak softening observed in Fig. 7. The specimen ultimately collapsed at a strain of 0.0058 mm/mm.

For WR-4, The behavior of this specimen is a little improved over the other single layer wrapped samples in terms of the post peak softening (Fig. 7). The sample ultimately collapsed at a strain of 0.0061 mm/mm with progressive yielding of the fabric sustained a maximum stress of 51.6 MPa at a strain of 0.00332. This sample showed a comparatively a stiffer post peak response which is desirable. The energy absorbed by this specimen is comparable to that of the WR-2 specimen even after collapsing at a lower strain value. The end failure is brittle with sudden collapse of the specimen (Fig. 8(d)). The specimen also developed white patches due to the debonding phenomenon. Crack propagation was observed to start from the centre slowly progressing towards top.

Further, the double layered WR wrapped sample showed some interesting observations. The overall strength achieved by the specimen is not high against the expected; the specimen could sustain a peak stress of only 48.59 MPa i.e. only a 27% increase over the control specimen compared to an average 34% increase in the case of single layered samples. The possible explanation of this could be that in the very early stage the specimen started to exhibit white patches (Fig. 8(e)) indicative of the debonding between the two layers of the fabric wrap and hence the strength obtained for the sample is in the range of single layer WR specimens (48-53 MPa) (Table 6). The energy absorbed was the largest in this case and was observed to be 200% more than the control specimen. The specimen showed highly improved ductile properties and the post peak hardening was much better than any of the single layer samples. This could be because of the increased thickness of the wrap (double layer).

(a)WR-1 (b) WR-2 (c) WR-3 (d) WR-4 (e) 2lay WR

Figure 8: Failure pattern of WR confined specimens

2.4.3 *Specimens confined with CSM*

Four specimens confined with CSM are tested in the similar setup as explained above for WR specimens, and the behavior of each specimen is individually recorded.

The stress strain curve of each specimen is obtained in the same way as for the control specimen, and is shown in Fig. 9. From Fig. 9, it can be observed that the post peak behaviour for the CSM confined specimen is different from that of the control specimen. The peak loads and energy absorption capacity of confined specimens are higher than that of control specimen, which is is evident from the normalized stress vs strain curves shown in Fig. 9. The energy absorbed by the samples is very important in enhancing its life under any kind of load, especially under seismic loads. The greater the energy absorption the greater is the duration for which a specimen can sustain a given type of load. The area under any stress-strain curve gives an idea of the energy absorbed by the specimen during loading. Table 7 gives details on the increase in loading capacity and energy absorption capacity of CSM confined and unconfined concrete specimens.

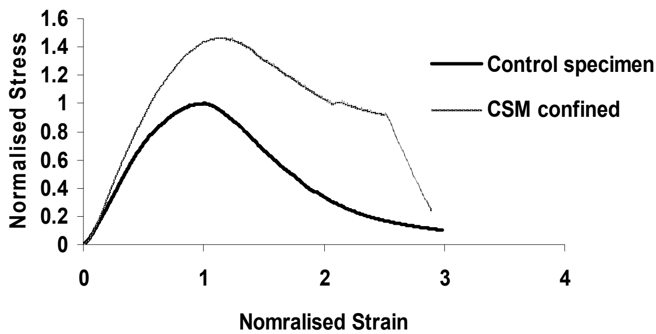

Figure 9: Normalised stress strain curve of control and CSM specimen.

Table 7: Comparison of CSM confined and unconfined concrete specimens

Material	Peak stress value (MPa)	Energy (x10^6J/m^3)	% increase in energy absorption compared to control specimen	% increase in strength compared to control specimen
Control specimen	38	0.15678	46	36
CSM confined specimen	55	0.22267		

2.4.3.1. Failure Pattern

Tensile rupture of the CSM is observed in the specimen. The CSM mat is splitted along the length of the concrete cylinder. The mat is peeled-off abruptly from the cylinder (Fig. 10). The post peak softening is also appreciable. An increase in strength is observed compared to control specimen and the sample failed at a peak stress of 55Mpa, i.e 1.5times that of the control specimen specimen's peak stress The failure can be noticed by drastic vertical drop in stress- strain curve of the sample as shown in the Fig. 9.

Figure 10: Failure Pattern in CSM

2.4.4 Specimens confined with textile reinforcement

A total of 3 concrete cylinders of 150 mm diameter and 300 mm in height, are confined with one layer of alkali resistant textile reinforcement. The stress-strain curves obtained from the experiments for each specimen are rendered in the form of representative normalized stress-strain graphs (Fig. 11). The normalization is done with respect to the ultimate stress and corresponding strain of a representative control specimen. Table 8 presents the details of average ultimate stress, ultimate strain and energy absorption for plain and confined systems. It is observed that there is about 4.5% increase in strength for textile reinforcement confined concrete specimens compared to control specimen. Further, the energy absorption capacity of the specimen confined with textile reinforcement is about 68% higher than that of control specimen.

Table 8: Comparison between plain and textile reinforced confined system

Specimen Type	Ultimate stress (MPa)	Energy absorption (x10^6 J/m^3)
Control specimen	38.41	0.16
Specimen confined with textile reinforcement	40.08	0.27

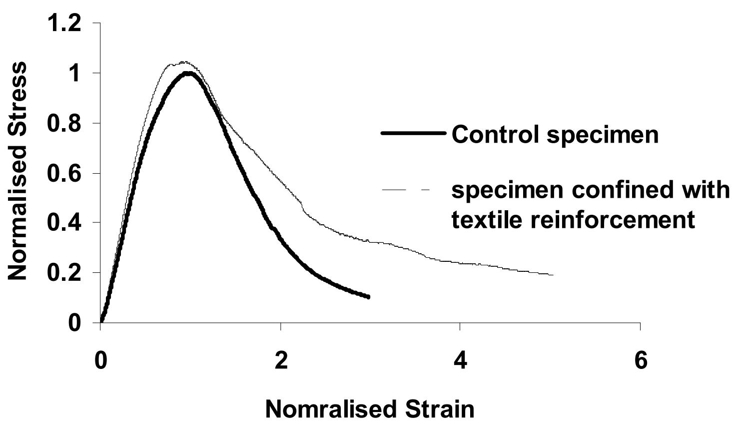

Figure 11: Stress-strain of confined and unconfined specimens

Regarding mode of failure, it has been observed that failure initiated in the mesh region of fabric and ultimate failure is occurred by spalling of concrete in the same region. Fig.12 shows the failure pattern of concrete specimen confined with textile reinforcement.

3 Summary and Conclusions

Investigations on confinement effect for concrete specimen using different glass fabrics such as woven roving, chopped strand mat and textile reinforcement have been carried out. Experimental investigations have been performed on concrete

Figure 12: Compression failure of specimen confined with textile reinforcement

cylindrical specimens of diameter 150mm and height 300mm. Displacement controlled experiments are conducted for control as well as confined specimens. Main observations from experimental study are summarized below.

(a) For WR confined specimens

Approximately 35% increase in strength is observed by means of single layered wrapping of the given fabric and proved that confinement using E-Glass woven roving fabric results in considerable improvement in load bearing capacity over unconfined one.

Energy absorption is increased by 200% with double layer confinement and 153% with single layer confinement of the given fabric. This effect is especially advantageous in case of seismic strengthening of structures.

The end failure in each case is brittle mainly because of increased energy absorption and sudden release of energy.

White patches indicated the debonding of fabric from concrete surfaces before sudden failure and can be assumed as warning signals before the collapse.

(b) For CSM confinement

About 36% increase in strength by wrapping the cylinders with CSM compared to the control specimen is observed which shows considerable improvement in load bearing capacity.

Energy absorption is increased by 46% compared to control specimen.

The end failure is brittle due to sudden release of energy and the failure pattern observed was abrupt peeling-off of CSM from the surface.

(c) For specimens confined by textile reinforcement

There is about 4.5% increase in strength for specimens confined with textile reinforcement compared to control specimens

The energy absorption capacity for these specimens are about 68% higher than that of control specimen.

Specimens confined with textile reinforcement initiated failure in mesh region of fabric and ultimate failure has been by spalling of concrete in the same region.

From the investigations, it is concluded that to avoid the debonding and abrupt failure, textile reinforcement is the best option compared to woven roving and chopped strand mat. But the strength enhancement is comparatively low for this material and reducing the mesh size may increae the confinement effect. In the present investigation, full potential of the textile reinforcement is not exploited and further research is needed in this direction for generalization of behaviour of textile reinforced specimens.

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References

Ahmad, S.M.; Khaloo, A.R.; Irshaid, A. (1991): Behavior of concretespirally confined by fiberglass filaments. *Mag. Concrete Res.,* vol. 43, no. 156, pp.143–148.

Coronado, C.A.; Lopez, M.M. (2007): Damage approach for the prediction of debonding failure on concrete elements strengthened with FRP. *Journal of composites for construction ASCE*, vol. 11, no. 4, pp.391-400.

Engindeniz, M.K.; Lawrence, F. (2005): Repair and strengthening of reinforced concrete beam-column joints: state of the Art. *ACI Struct jnl*, vol.102, pp.187-197.

Fam, A.Z.; Rizkalla, S.H. (2000): Concrete-filled FRP tubes for flexural and axial compression members. Proc., ACMBS-3. Ottawa, Canada, pp: 315–322.

Fardis, M.N.; Khalili. H. (1981): Concrete Encased in Fibre Glass-Reinforced Plastic. *ACI Materials Journal*, vol. 78, no. 5, pp. 440-446.

Fardis, M.N.; Khalili, H. (1982): FRP-encased concrete as a structural material. *Mag. Concrete Res*, vol. 34, no.121, pp. 191–202.

Franz, T.; Nurick, G.N.; Perry, M.J. (2002): Experimental investigation into the response of chopped strand mat glassfibre laminates to the blast loading. *International journal of impact engineering,* vol. 27, pp. 637-669.

Gu, H.; Zuo, Z. (2006): Compressive behaviors and failure modes of concrete cylinders reinforced by glass fabric. *Materials and Design*, vol. 27, pp.601-104.

Harmon, T.G.; Slattery, K.T. (1992): Advanced composite confinement of concrete. 1st Int. *Conf. on Advanced Composite Materials in Bridges and Structures*, Sherbrooke, Que, Canada, pp: 299–306.

IS:10262-1982 (2004): (Reaffirmed 2004). Indian Standard Recommended Guidelines for concrete mix design. Bureau of Indian Standards, New Delhi.

Kurt, C. E. (1978): Concrete filled structural plastic columns. *J. Struct. Div.* ASCE, vol. 104, no. 1, pp. 55–63.

La Tegola, A.; Manni, O. (1999): Experimental investigation on concrete confined by fiber reinforced polymer and comparison with theoretical model. *Proc., FRPRCS-4*, Baltimore, pp. 217-228

Lam, L.; Teng, J.G. (2003): Stress-Strain Model for FRP-Confined Concrete for Design Application. 6th International Symposium on *Fiber Reinforced Polymer Reinforcement for Concrete Structures* (FRPRCS-6), K. H. Tan, ed., 2, pp. 601-612.

Matthys, S.; Taerwe, L.; Audenaert, K. (1999): Tests on axially loaded concrete columns confined by fiber reinforced polymer sheet wrapping. *Proc., FRPRCS-4*, Baltimore, pp: 217–228.

Micelli, F.; Myers, J.J.; Murthy, S. (2001): Effect of environmental cycles on concrete cylinders confined with FRP. In Proc., CCC2001 *Int. Conf. on Composites in Construction*. Porto, Portugal .

Miyauchi, K.; Nishibayashi, S.; Inoue, S. (1997): Estimation of strengthening effects with carbon fiber sheet for concrete column, Non-Metallic (FRP) Reinforcement for Concrete Structures. *Proceedings of the Third International Symposium*, vol. 1, pp. 217–224.

Nanni, A.; Bradford, N.M. (1995): FRP jacketed concrete under uniaxial compression. *Constr. Build. Mater,* vol. 9, no. 2, pp.115–124.

Picher, F.; Rochette, P.; Labossie're, P. (1996): Confinement of concrete cylinders with CFRP. Proc., ICCI'96. Tucson, Ariz. pp: 829–841.

Rochette, P.; Labossie're, P. (2000): Axial testing of rectangular column models confined with composites. *J. Compos. Constr*., vol. 4, no.3, pp.129–136.

Rousakis, T. (2001): Experimental investigation of concrete cylinders confined by carbon FRP sheets, under monotonic and cyclic axial compressive load. Research Rep., Chalmers Univ. of Technology, Go¨teborg, Sweden.

Saafi, M.; Toutanji, H.A.; Li, Z. (1999): Behavior of concrete columns confined with fiber reinforced polymer tubes. *ACI Mater. J*., vol. 96, no. 4, pp.500–509.

Smitha G, Ramachandra Murthy, A.; Bhaskar, S.; Ramesh kumar, V.; Nagesh R. I. (2012), Confinement effect of woven roving glass fabric on concrete specimens, CMC, vol.27, no.1, pp.73-99.

Tayeb, N.S.; Yousif, F.; Yap, T.C. (2008): An investigation on worn surfaces of chopped glass fibre reinforced polyester through SEM observations. *Tribology International*, vol. 41, no. 5, pp. 331-340.

Toutanji, H. (1999): Stress-strain characteristics of concrete columns externally confined with advanced fiber composite sheets. *ACI Mater. J.*, vol. 96, no.3,pp. 397–404.

Watanabe, K.; Nakamura, H.; Honda, Y.; Toyoshima, M.; Iso, M.; Fujimaki, T.; Kaneto, M.; Shirai, N. (1997): Confinement effect of FRP sheet on strength and ductility of concrete cylinders under uniaxial compression. *Proc., FRPRCS-3*, Sapporo, Japan, vol. 1, pp.233–240.

Wu, G.; Wu, Z.S.; Lu, Z.T. (2007): Design oriented stress-strain model for concrete prisms confined with FRP composites. *Construction and Building Materials,* vol. 21, pp.1107-1121.

Xiao, Y.; Wu, H. (2007): Compressive behavior of concrete confined by carbon fiber composite jackets. *J. Mater. Civ. Eng.,* vol.12, no.2, pp.139–146.

Ye, L.; Zhang, S.; Mai, Y.W. (1998): Strengthening Efficiency of E-Glass Fibre Composite Jackets of Different Architectures for Concrete Columns. *Applied Composite Materials*., vol 5 , no.2,pp. 109-122.