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STRENGTHENING OF COLUMN USING CFRP

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Abstract - *In some buildings, when quality control is poor, the columns have a weak compressive strength, particularly in floor zone. Low compressive strength of the column member will lead to reduction in bearing capacity of column. This project is carried out to investigate the overall actions of P.C.C cylinder, strengthened with wrapped CFRP. From the literature study One or two of them will be a control specimen and the other six specimens were strengthened with CFRP. The main parameters studied from the literature research were the compressive strength, and the height of CFRP wrapped part of column. The results include mode of failure, ultimate load. All the test specimens were loaded to failure in axial compression and the behaviour of the specimens in the axial directions was investigated. Test results exposed that the CFRP wrap increases the strength and ductility of plain and RC cylinders expressively. The main conclusion of this project was, strengthening of column using CFRP and which may give good results of the column load carrying capacity.*

***Key Words*: CFRP, Debonding, Adhesive, Concrete Columns, Compression**

1. GENERAL BACKGROUND

Retrofitting of existing civil engineering structures has been undergoing intense study in recent times. Time induced deterioration of existing structures, degradation due to environmental impacts, poor initial design and construction, lack of maintenance, and sudden events like earthquake indicates structural strengthening as a viable necessity. With the recent developments in material science, methods and techniques for structural strengthening have been diverse. One of today's state-of-the-art techniques are the use of Fibre Reinforced Polymer (FRP) composites, which are currently being viewed by as highly promising materials in the construction. The durability of concrete structures has always been an issue of great concern especially related to the corrosion of steel reinforcement. Coastal structures, ports, chemical industry facilities, and bridges are examples of critical structures subjected to reinforcement corrosion. Using Carbon Fibre Reinforced Polymer (CFRP) as supplemental reinforcement could be an option.

In some buildings, when quality control is poor, the columns have a weak compressive strength, particularly in floor zone. Low compressive strength of the column member will lead to reduction in bearing capacity of column. This paper is carried out to investigate the overall actions of R.C columns, strengthened with wrapped CFRP. From the literature study One or two of them will be a control specimen and the other six specimens were strengthened with CFRP. The parameters considered are the number of composite layers and the compressive strength of unconfined concrete.

Fiber-Reinforced polymer(FRP), also is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, carbon, or aramid, although other fibers such as paper or wood or asbestos have been sometimes used sometimes used. FRPs are commonly used in the aerospace, automotive, marine, and construction industry. The behaviour of FRP wrapped concrete cylinders with different wrapping materials and bonding dimensions has been studied. It was found that the load-carrying capacity of the wrapped concrete structure is governed by mechanical properties such as tensile elasticity modulus and Poisson's ratio of the wrapping sheet.

1.1 FRP types and applications

Fiber reinforced plastic (FRP), also known as fiber reinforced polymer, is a composite material consisting of a polymer matrix reinforced with fibers. Fibers are usually aramid, fiberglass, or carbon, while the polymer is usually a vinyl ester, polyester thermosetting plastic, or epoxy.

Fig 1.1 shows a stress-strain comparison between steel and various FRPs. It shows that CFRP have similar stiffness to steel, while AFRP and GFRP have lower stiffness compared to steel. Both CFRP and AFRP have high strength compared to GFRP. Comparing the FRP modes of failure against steel, it is clear that all FRP have a brittle failure mode, while steel has its well-known ductile behavior.

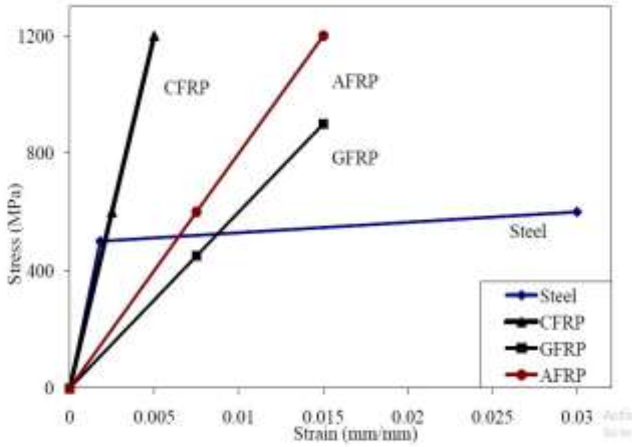

Fig.1.1: Comparison of stress-strain behavior of steel and FRPs

1.1.1AFRP

Aramid fiber reinforced plastic (AFRP) is a composite material made of plastic reinforced with fine aramid fibers. Like any reinforced plastic, the composite material is commonly referred to by its reinforcing fibers, aramid in this case. AFRP filaments are produced by extrusion of the precursor through a spinnert. Extrusion imparts anisotropy (increased strength in the lengthwise direction) to the filaments. The most popular matrix materials for manufacturing AFRP are thermosets (polymers which do not melt when heated) such as epoxies, vinylester, and phenolics. Aramid may protect carbon fibers and improve their properties. Hybrid fabric (Aramid + carbon fibers) combines very high tensile strength with high impact and abrasion resistance.

1.1.2 GFRP

Glass fiber reinforced plastic (GFRP) is a composite material made of plastic reinforced with fine glass fibers. Like graphite-reinforced plastic, the composite material is commonly referred to by the name of its reinforcing fibers (fiberglass). The plastic is thermosetting (polymer materials that irreversibly cure form), most often polyester or vinylester, but other plastics, such as epoxy are also used. The glass is mostly in the form of chopped strand mat (CSM), but woven fabrics are also used. CSM is a form of reinforcement used in glass-reinforced plastics. It consists of glass-fibers laid randomly across each other and held together by a binder.

1.1.3 CFRP

Carbon fiber reinforced polymer (CFRP) is a kind of polymer matrix composite material reinforced by carbon fibers. The reinforcing dispersed phase may be in the form of either continuous or discontinuous carbon fibers, commonly woven into a cloth. Carbon fibers are expensive but they possess the highest specific mechanical properties per weight, such as modulus of elasticity and ultimate strength. Carbon fibers are used for reinforcing the polymer matrix due to their following properties: Very high modulus of elasticity, exceeding that of steel; High tensile strength, which may reach 7 GPa; Low density:1800 kg/m^3; High chemical inertness.

Carbon fiber materials are commonly produced as dry fiber tow sheets. The sheets can be impregnated with a saturating resin on-site using a wet lay-up technique and are well suited for curved applications or highly irregular surfaces. For applications requiring a higher degree of strengthening, the carbon fibers can also be pultruded into a precured laminate, which can subsequently be bonded to the surface of the structure using a structural adhesive. The main disadvantage of carbon fibers is their catastrophic mode of failure, since carbon fibers exhibit a brittle mode of failure.

CFRP is a more costly material than its counterparts GFRP and AFRP, though CFRP is generally regarded as having superior properties. Much research continues to be done on using CFRP both for retrofitting and as an alternative to steel as a reinforcing or prestressing material. Cost remains an issue and long-term durability questions remain. Though design codes have been drawn up by institutions such as the American Concrete Institute, there remains some hesitation among the engineering community in regards to implementing these alternative materials.

1.2 Structural characteristics of CFRP

The material properties of the CFRP laminates have been greatly improved over the last few years, with a wide variety of dimensions and strengths required to achieve significant stiffness increases. More recently, CFRP materials with a modulus of elasticity approximately twice that of structural steel have become available. Several researchers have indicated that these materials can be used to increase the strength and stiffness of steel-concrete composite beams. Consideration of the CFRP plate end debonding as critical failure mode should be avoided to prevent an undesirable failure of the system. Debonding strength of steel beams strengthened with CFRP sheets

1.3 Objectives

The objective of this research is to quantify the load improvement using novel CFRP configurations and develop design guidelines for using CFRP sheets to strengthen RCC columns.

The objectives of this research:

- To determine the structural behaviour of P.C.C. columns wrapped with carbon fibre of to enhance the compressive strength of the columns along with the existing practice of doing the repair work.
- It is the comparative study of compressive strength between plain cement concrete, cement concrete with admixture, cement concrete with CFRP sheet and cement concrete with admixture and CFRP sheet.

1.4 Scope of study

- The scope of this research is limited to the strengthening of RCC columns in compression.
- FRP strengthening provides an ideal system for achieving the strength and ductility requirements of new constructions as well as existing structures.
- Columns occupy a vital role in the load transfer mechanism of all structures.
- Essential to reduce hazard and losses from structural elements.
- Predominantly concerned with structural improvement to reduce seismic hazard.

1.5 Methodology

- Literature review
- Calculation of ultimate load carrying capacity of P.C.C cylinder.
- Testing of P.C.C. cylinder with and without CFRP and admixture under uniaxial compression.
- Testing of P.C.C. cylinder.
- Testing of P.C.C. cylinder strengthened with CFRP in the cross section of the cylinder.
- Testing of admixture added P.C.C. cylinder under uniaxial compression.
- Testing of admixture added P.C.C. cylinder strengthened with CFRP in cross section of cylinder.
- Comparison of the compressive strength of the above specimens.

2. LITEARTURE REVIEWS

2.1 Studies on previous literature

D. Vigneshkumar (IJRET, 2018) : This paper is carried out to investigate the overall actions of R.C columns, strengthened with wrapped CFRP.The overall response of the wrapped concrete cylinders was superior to that of the unwrapped cylinders subjected to the same environmental conditions. The CFRP wrapped specimen showed significant improvement in terms of strength, stiffness. and ductility in comparison to a similar unwrapped cylinder.

K. Olivova, J. Bilcik (SJCE,2008) : In this paper the author uses fiber reinforced polymer (FRP) materials for structural repair and strengthening has continuously increased in recent years, due to several advantages associated with these composites when compared to conventional materials like steel. This paper presents the results of an experiment at study on the structural behavior of reinforced concrete columns strengthened with carbon fibre sheets.

K. P. Jaya, Jessy Mathai (WCEE, 2012): This paper includes a study on Seismic retrofitting of constructions vulnerable to earthquakes is a current problem of great political and social relevance. Most of the Indian building stock is vulnerable to seismic action even if located in areas that have long been considered of high seismic hazard. Hence, experiments were conducted on Reinforced concrete columns with and without FRP wrapping.

2.2. SUMMARY OF LITERATURES

All previous studies on strengthening P.C.C. cylinder with CFRP plates/sheets proved that it could provide an enhanced strength to the member. The literatures, also pointed out the great significance of CFRP bonding. Even though there are limited uses of CFRP plates to strengthen and rehabilitate structures, further research is needed to provide confidence in the usefulness of the material.

3. MATERIALS AND PROPERTIES

3.1. INTRODUCTION

The materials used for the experimental study and their properties are explained below. The main materials used are Sikament, CFRP sheet and epoxy adhesive.

3.2. SUPERPLASTICIZER (SIKAMENT)

Superplasticizer is also known as high range water reducing admixture. Superplasticizer reduces three to four times water content in given concrete mixtures compared to the mixture containing normal water reducing admixture. Superplasticizer helps in lowering the water-cement ratio so it contributes to enhancing the durability of concrete. The chloride content in admixture shall be declared by the manufacturer. Superplasticizers are expected to be chloride free. Admixtures which contain relatively high chloride content may accelerate the rate of corrosion in prestressing steel.

Superplasticizer consists of the long chain, high molecular weight anionic surfactants with a large number of polar groups in the hydrocarbon chain. Superplasticizer adsorbed on cement particles and imparts a strong negative charge, which helps the surface tension of the surrounding water considerably and enhances the fluidity of the mix. Generally mixes with superplasticizer do not encounter segregation because of the colloidal size of the long chain particles of the admixture that obstructs the bleed water flow channels in concrete. Superplasticizer creates well dispersion of cement particles in water and accelerates the rate of hydration. Rapid loss of the consistency or slump was observed with use of the first-generation superplasticizer. Polyacrylates, polycarboxylic, and polyethylene based copolymers are new generation superplasticizer, which has comb-like molecular structures.

In steric repulsion, one side of the polymer chain gets adsorbed on the surface of the cement particle, while the long unabsorbed side creates the steric repulsion. The grafted side chains of comb superplasticizers protrude and extend from the adsorbed cement surface site to hinder neighboring cement particles to reach the range within which vander Waal's force of attraction would be effective. Effects of steric repulsion last longer than electrostatic repulsion, therefore at lower dosage new generation superplasticizers have greater influence over the slump retention compared to naphthalene or melamine-sulfonate type superplasticizers.

- sikament is a high range water- reducing and set retarding concrete admixture
- It is a substantial water reducing agent for promoting high early and ultimate strengths
- Sikament® -R2202 is used wherever high quality concrete is demanded under difficult placing and climatic conditions.

Sikament® -R2002 provides the following properties:

As a Super Plasticizer:

- Substantial improvement in workability without increased water or the risk of segregation.
- Long lasting.
- control of slump loss.
- No adverse effect on ultimate strengths.

As a Water Reducer:

- Early strengths significantly increased.
- High ultimate strengths.
- Up to 15% water reduction. Especially suitable for hot climates.
- No excessive air entrainment.
- No adverse Shrinkage effect.
- Improved surface finish.
- Increased water tightness.
- Chloride free-does not attack reinforcement.

Colour : Brown Liquid
Density :(at 20°C) 1.185 (ASTM C-494)

3.3. CFRP SHEET

It is an extremely strong and light fiber reinforced plastic which contains carbon fiber(Fig. 3.3). CFRP sheets of 0.42mm thickness is used in the experimental study. For strengthening CFRP sheetsin 3 layers are used. The properties of CFRP sheets are:

Table 3.1 Properties of CFRP sheets

Tensile Strength (GPa)	3.45
Modulus of elasticity (GPa)	230
Percentage Elongation (%)	1.6
Density (g/cm^3)	1.8

Fig.3.1 CFRP sheet

3.4. ADHESIVE

The adhesive used is Araldite AW 106 epoxy resin with hardener HV 953 IN in order to bond CFRP sheet to concrete surface. Equal quantity by volume of epoxy resin and hardener is mixed thoroughly to get adequate bonding property. The properties of adhesive given by the epoxy adhesive is given in Table 2.

Table 3.2 Properties of epoxy adhesive

Viscosity	45000
Minimum cure time	12 hours
Shear strength (for 5 days curing)	17.6 MPa
Ultimate Tensile Strength	33 MPa
Elongation	9 %

Fig.3.2 epoxy adhesive

3.5. ORDINARY PORTLAND CEMENT (OPC)

OPC or Ordinary Portland Cement is the most widely used cement worldwide. It is used in formation of a number of construction essentials including concrete, stucco, mortars and many more. Being hydraulic cement, it not only reacts with water and forms a solid mass but also become water-resistant on curing. The formation of OPC takes place when clinkers of Portland cement are pulverized. These clinkers consist of hydraulic calcium silicates. Portland cement clinkers are produced by heating a mixture of limestone, iron ore, clay, fly ash, shale, sand, bauxite and slag at 1450°C. OPC reacts with water and hardens in to a solid form gradually.

Fig.3.3 OPC Cement

Because of huge availability of the raw material required for production of Ordinary Portland Cement or OPC, it is available in market at highly cost effective prices. Being a low cost yet optimum quality material, OPC is used for the construction of dams, roads, houses etc. throughout the world. Basically three grades of Ordinary Portland Cement are used in the construction process. These include 33 grade OPC, 43 grade OPC and 53 Grade OPC.

3.6. TEST METHOD

3.6.1. Cement

(a) Specific gravity

Specific gravity is the ratio of the weight of a volume of a particular material to the weight of the same volume of water at a specified temperature. Specific gravity of cement is calculated using Le Chateliers apparatus.

- Weight of cement used, W = 60g
- Initial reading of flask, V_1 = 0ml
- Final reading of flask, V_2 = 19.5ml
- Specific gravity of cement = Weight of cement used / Weight of equal volume of water

$$= W/(V_2 - V_1)$$
$$= 60/(19.5 - 0)$$
$$= 3.076 \sim 3.1 \text{ g/cc}$$

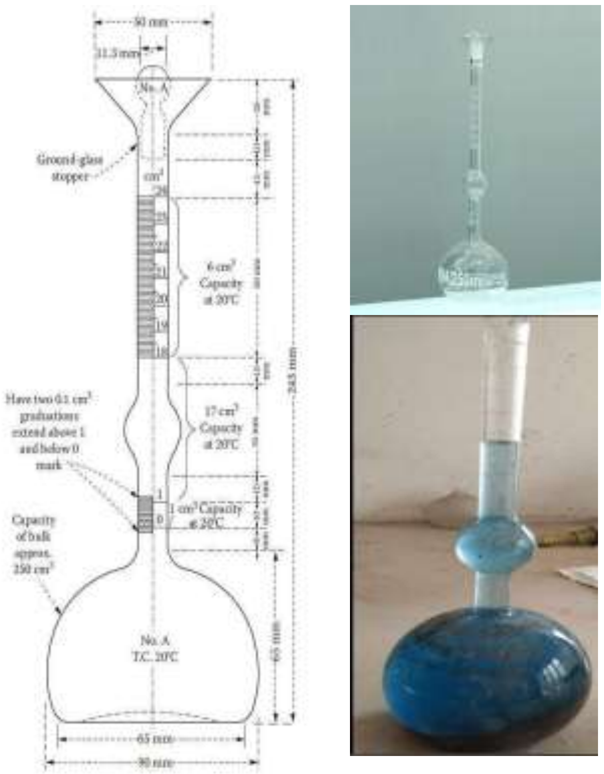

Fig.3.4 (a) Lechatelier's flask

(b) Consistency

The standard consistency of cement is that consistency, which permit the vicat plunger to penetrate to a point 5 to 7mm from the bottom of the vicat mould when tested.

Fig.3.4 (b): Vicat apparatus

Table 3.3: Water content v/s depth of penetration

Sl. no.	% of water added	Depth of penetration
1	35	0
2	32	6

- Weight of cement taken (g) = 400g
- Initial percentage of water added to cement = 35%
- Percentage of water content for standard consistency = 32%

3.6.2. Coarse Aggregate

(a) specific gravity

Ratio of the weight of an object to the weight of an equal volume of water at standard temperature and pressure

Fig.3.5 (a):Wire mesh basket

- Weight of sample in water, w_1 = 3.2 kg
- Weight of empty basket in water, w_2 = 2kg
- Weight of sample, w_3 = 2kg
- Apparent specific gravity = Weight of sample / weight of water

$= w_3 / w_3 - (w_1 - w_2)$

$= 2 / 2 - (3.2 - 2)$

$= 2.5$

(b) Grain size analysis

Table 3.4: Distribution of Coarse aggregate

Designation of sieve (mm)	Sieve opening (mm)	Weight retained	% weight retained × 100/1000	Cumulative % weight retained	% finer
25	25	0	0	0	100
20	20	236	23.6	23.6	76.4
12.5	12.5	685	68.5	92.1	7.9
10	10	71	7.1	99.2	0.8
4.75	4.75	8	0.8	100	0
Pan	Pan	0	0	0	0

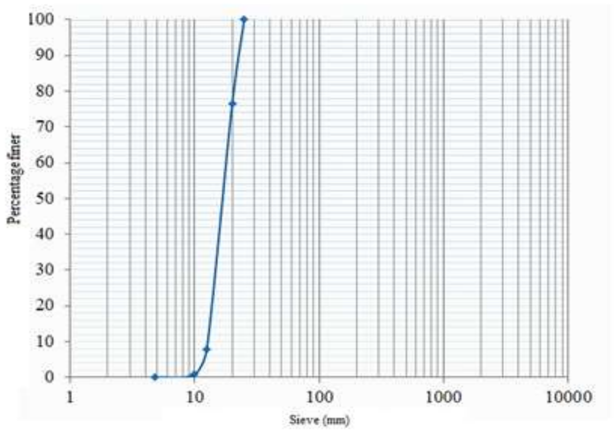

Fig.3.5 (b): Particle size distribution curve

D60/D10 = 17/ 12.9 = 1.31

3.6.3 Fine aggregate

(a) Specific gravity

Specific gravity is a measure of a material's density (mass per unit volume) as compared to the density of water at 73.4°F (23°C). Therefore, by definition, water at a temperature of 73.4°F (23°C) has a specific gravity of 1.

Aggregate specific gravity is used in a number of applications including superpave mix design, deleterious particle identification and separation, and material property change identification. Specific gravity can also indicate possible material contamination.

Specific gravity of fine aggregate by pycnometer method:

Fig 3.6(a): pycnometer jar

- Weight of sample = w2 = 500g
- Weight of water + weight of sample + weight of water = w1 = 1500g
- Weight of water + weight of pycnometer = 1200g
- Apparent specific gravity = w2 / w2 - (w - w1)
  = 500 / 500 -(1500 - 1200)
  = 2.5

(b) Grain size analysis

1) **Table 3.5:** Distribution of fine aggregate

Designation of sieve	Sieve opening (mm)	Weight retained	% weight retained × 100/1000	Cumulative % weight retained	% retained
4.75mm	4.75	12	1.2	1.2	98.8
2.36mm	2.36	51	5.1	6.3	93.7
1.18mm	1.18	157	15.7	22	78
600µ	0.6	203	20.3	42.3	57.7
300µ	0.3	221	22.1	64.4	35.6
150µ	0.15	216	21.6	86	14
Pan	Pan	140	14	100	0

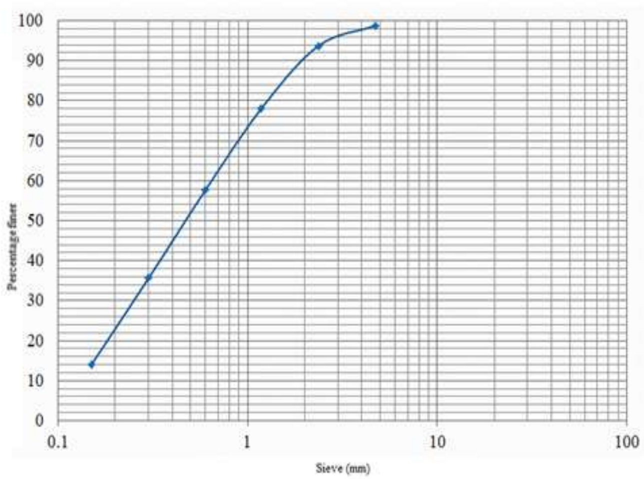

Fig.3.6 (b_1): Particle size distribution curve of fine aggregate

D60/ D10 = 0.68 / 0.13 = 5.23

Fig.3.6 (b_2): Sieves

3.7MIX DESIGN FOR M30 GRADE OF CONCRETE

Ingredient	Water (kg)	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)
Quantity	186	372	1078.17	703.98
Ratio	0.5	1	2.99	1.89

4. EXPERIMENTAL STUDY

4.1.INTRODUCTION

This chapter deals with the details of the specimens used, procedure adopted for strengthening of the specimens, test for the experimental study and the results obtained. Four sets of 3 specimens each are prepared and strengthened with CFRP and admixture

Sikament R2002. For each of the 4 sets, 2 set of specimens are given CFRP covering. For the other 2 sets admixtures are added. One set is common which contain both CFRP and Sikament R2002 admixture. The rest one set is plain cement concrete. All the column specimens are subjected to compression test till failure. The following laboratory tests are conducted: Compressive strength at 7 days and 28days.

4.2.SPECIMEN DETAILS

The strengthening effectiveness of CFRP sheets on P.C.C. and admixture added cylinders were studied by testing 24 cylinders. One of them is plain cement concrete and served as a bench mark cylinder. Fig.4.1 shows the cylinder specimens.

Fig.4.1: Cylinder Specimen

4.3. SPECIMEN PREPARATION AND PROCEDURE

The cylinder is of 0.3m height and 0.15m diameter. The dimensions were properly checked using a meter scale.

- CFRP confined cylinder preparation: The surface of the specimen was cleaned thoroughly to remove loosely held powders and was then cleaned with water and left to dry before wrapping.
- Before wrapping the concrete surface was coated with a mixture of equal quantities of epoxy primer and epoxy resin.
- The CFRP sheet is then wrapped around the specimen (Fig.4.2).

Fig.4.2: CFRP Wrapped specimen

4.4.TEST SETUP

The following processes were carried out for the preparation of the specimens. The cleaned CFRP strips were glued to the sides of the column of the specimens at the required positions. A certain amount of admixture(1000ml/100kg of cement) is added to the specimens. After one week, after the adhesive has hardened the test procedures were carried out (Fig.4.3)

Fig.4.3: Compression test on CFRP Wrapped cylinder Specimen

4.5.TEST RESULT

The compressive strength of cylinder is given in Table 7

Table 4.1:Test result

Sl. No.	Material	Types	No. of Samples	Compressive strength After 7 days curing (kN/mm^2)	Average strength of 7 days curing (kN/mm^2)
1	Conventional	Unwrapped	3	15.98 14.27 14.74	14.99
2	CFRP	Wrapped 1 layer	3	24.29 22.58 23.05	23.30
3	SIKAMENT R2002	1% added	3	22.88 22.27 24.54	23.23
4	CFRP & SIKAMENT R2002	Wrapped 1 layer & 1% admixture added	3	31.19 30.01 31.54	30.91

Table 4.2:Test result

Sl. No.	Material	Types	No. of Samples	Compressive strength After 28 days curing (kN/ mm^2)	Average Strength of 28 days curing (kN/ mm^2)
1	Conventional	Unwrapped	3	23.5 21.3 22.01	22.27
2	CFRP	Wrapped 1 layer	3	30.3 29.61 30.32	30.07
3	SIKAMENT R2002	1% added	3	34.68 33.24 36.10	34.67
4	CFRP & SIKAMENT R2002	Wrapped 1 layer & 1% admixture added	3	42.99 43.55 44.41	43.65

5. RESULTS AND DISCUSSIONS

The overall response of the wrapped concrete cylinder was superior to that of unwrapped cylinder subjected to same environmental conditions. The CFRP wrapped specimen showed significant improvement in terms of compressive strength in comparison to similar unwrapped cylinders.

Comparison of compressive strength of cylinder specimens after 7 day curing:

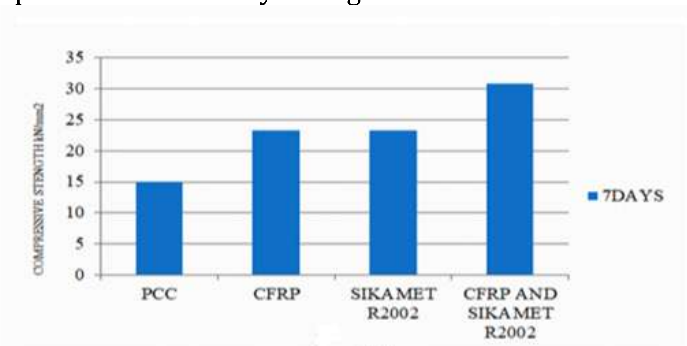

Fig.5.1: Comparison of compressive strength after 7 day curing

From above comparison we can see that introduction of CFRP and Sikament admixture has increased the overall compressive strength of the cylinder specimen on comparing with the unwrapped concrete cylinder. The increase in compressive strength of cylinder specimen with CFRP and Sikament R2002 admixture is approximately 75% more than the normal concrete cylinder specimen.

Comparison of compressive strength of cylinder specimens after 28 day curing:

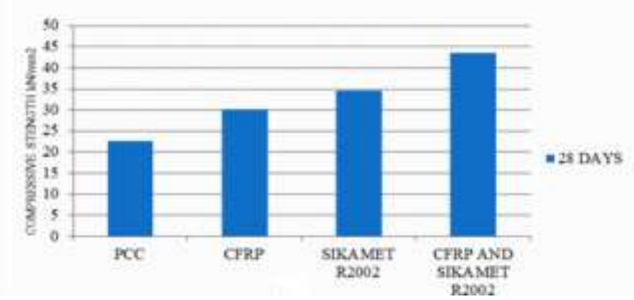

Fig.5.2: Comparison of compressive strength after 28 days curing

The above graph compares compressive strength values of 28 day cured cylinder specimens. The installation of CFRP fabric has increased the compressive strength up to 71.27% than the normal concrete cylinder specimen.

On comparing the graphs Fig.5.1 and Fig.5.2 we can see that there is slight increase in specimen containing Sikament admixture than CFRP wrapped specimen after 28 days curing. Whereas after 7 days curing the compressive strength is almost same in the above mentioned specimens. This increase is due to the various characteristics like up to 15% water reduction, early strength, no adverse shrinkage effect, increased water tightness.

6.CONCLUSIONS

In general, CFRP sheets were very effective in strengthening of concrete columns after the addition of admixture SIKAMENT R2002. Based on the test results the following conclusions were drawn:

- Conventional concrete without any admixture and CFRP attains 74.23% compressive strength.
- The conventional concrete wrapped in 1 layer of CFRP attains 26% more strength than the conventional concrete withoutany admixture or CFRP. This proves that CFRP can be used to strengthen the column that hasn't achieved enough strength in 28 days. It can also be used in the renovation of old

buildings, for example old buildings having less strength in the columns and slabs can be increased in strength using CFRP where it provides the advantage of not demolishing the building.

- The percentage increase in compressive strength after adding admixture SIKAMENT R2002 to conventional concrete is 41.33%. The strength of the cylinder increased 1.55 times the original value, this concludes that the admixture used is good quality.
- There is a total of 45.3% increase in the compressive strength cylinder containing admixture and CFRP wrapping compared with conventional concrete with CFRP wrapping only. The percentage increase indicates that the strengthening technique proposed is promising for increasing the load carrying capacity of concrete columns failing in compression.

REFERENCES

[1] **Bogdanovic A.** (2002) Strengthening Circular Concrete Columns Using FRP SheetsApplications.The University of Manitoba, *Composite Materials in Civil Engineering*, 2002.

[2] **Mirmiran A. – Yuan, W. – Chen X.** (2002) Design for Slenderness in Concrete Columns Internally Reinforced with Fiber-Reinforced Polymer Bars. *ACI Structural Journal*, January – February 2002, pp. 116-125

[3] **De Lorenzis L.** (2001) A Comparative Study of Models on Confinement of Concrete Cylinders with FRP Composites. Chalmers University of Technology, *Work No.46, Goteborg 2001*

[4] **De Sena Cruz J.M.** (2005) Strengthening of Concrete Structures with Near-Surface Mounted CFRP Laminate Strips. PhD. Thesis, Universidade do Mindo, Departamento de Engenharia Civil, Azurém, Portugal, 2005.

[5] **De Paula R.F. - da Silva M.G.** (2002) Sharp Edge Effects on FRP Confinement of RC

[6] **De Lorenzis L. – Tepfers R.** (2000) Applicability of FRP Confinement to Strengthen Concrete Columns. Nordic Concrete Research, Publication No. 31. *The Nordic Concrete Federation 1/2004.* Oslo, June 2004, pp. 64-72

[7] **Karbhari M. – Douglas A.E.** (1995) Effects of Short Term Environmental Exposure on Axial Strengthening Capacity of Composite Jacketed Concrete.*American Society for Testing and Materials*, 1995.

[8] **Mirmiran A. – Yuan W. – Chen X.** (2002) Design for Slenderness in Concrete Columns Internally Reinforced with Fibre-Reinforced Polymer Bars. *ACI Structural Journal*, January – February 2002, pp. 116-125

[9] **Miyauchi, K. - et al.** (1999) Strengthening Effects of Concrete Column with Carbon Fibre Sheet. *Transactions of the Japan Concrete Institute vol. 21*, 1999, pp. 143 - 150

[10] **K. Zhang** (2003). Experimental study on seismic strengthening of RC columns with wrapped CFRP sheets. *Construction and Building Materials*, 17 (6 - 7).