Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, No.1, May : 2024

EVALUATION OF COMPRESSIVE STRENGTH OF GLASS FIBER REINFORCED CONCRETE

Brajesh Prajapati, Research Scholar, Department of Civil Engineering, Technocrats Institute of Technology Excellence, Bhopal.
Harish Nema, Suraj Mishra, Asst. Professor, Department of Civil Engineering, Technocrats Institute of Technology Excellence, Bhopal.
Ravindra Gautam, Professor, Department of Civil Engineering, Technocrats Institute of Technology Excellence, Bhopal

Abstract
Chopped Glass fiber has recently gained popularity in concrete reinforcing applications due to its environment friendly manufacturing process and excellent mechanical properties. This study investigates the compressive strength of GFRC with plain M-25 grade of concrete. Then influence of 0%,1%, 2% and 3% glass fiber content added to concrete by weight of cement Fiber cut length this 10mm and diameter 7 micron, is investigated to evaluate the strength properties of concrete. Based on laboratory tests, it has been observed that at 2% addition of glass fiber by weight of cement had a little effect on compressive strength of concrete.
Keywords: GFRC, Reinforced concrete, Glass Fiber, Compressive Strength, etc.

I. Introduction

Cement concrete is a most widely used construction material in the world over which generally consists of cement, aggregates (fine and course) and water. It is the material, which is used more than any other man-made material on the earth in construction industry. It is not easy to point out another material of construction which is as adaptable as concrete. It is the material of preference where strength, performance, serviceability, durability, fire resistance and abrasion resistance are required .It is so strongly associated now with every human activity that it touches every human being in his day to day living. It is one of the outwardly simple but actually complex construction materials. Many of its complex behaviors are yet to be identified to employ cement concrete advantageously and economically in the field. The behavior of concrete with respect to creep, bond, fatigue, fracture mechanism and polymer modified concrete, cellular concrete, fibrous concrete are some of the points of active research in order to have a deeper understanding of the complex behavior of concrete
(Patel and Chandak 2020).In the concrete, cement chemically reacts with water and produces binding slurry that binds other component of concrete together and creates hard material. There action process is called 'hydration of cement' in which water is absorbed by the cement. In this process of hydration some amount of lime [Ca(OH)2] is also liberated. The coarse and fine aggregates act as filler in the concrete mix. The major factors which determine the strength of concrete mix is amount of binding material used and the ratio of water to cement in the concrete mix. However, there are some factors which limit the quantity of cement and ratio of water / cement to be used in the concrete. This hydration process of cement in the concrete is exothermic and large amount of heat is liberated during process. Higher will be the cement content more will be the heat liberation leading in distress to Concrete overall. Water is the most important constituent of the concrete mix, once the concrete is hardened, the entrapped water in the concrete mix is used by cement for hydration and some water is evaporated, thus leaving pores in the cement matrix. Some fraction of these pores of cement concrete matrix is filled with hydrated products of cement paste. It has been experiential observation that higher the ratio of water / cement in the concrete mix, higher is the porosity of concrete structure resulting in increased permeability of the concrete structure(Awasthi and Choubey 2015).Use of Portland cement in making of concrete started about 190 years ago. The concept of high strength mean higher durability developed with low-grade cement included surety of performance and Portland cement became unique construction material of construction industry.

After the World War II, the need of speedy construction requires the development of high-grade Dicalcium Silicate (C2S) and increasing the binding properties of the cement with due respect of time. These percentage changes of silicate have resulted in high early strength rather than high strength cement. It has been found out that structure constructed using high grade cement during 1945-50 have distress within span of 15 to 20 years.
(Abdullah et. al. 2022) When the detailed analysis of concrete structure was carried out, it was revealed that As the hydration of cement takes place gradually in the mix, lime is also liberated gradually. A small quantity of liberated lime in the concrete mix is used to main a in pH of the concrete mix and the major portion remains unused/ surplus and makes pores in concrete matrix.The high-grade of cement releases higher amount of surplus lime resulting pores in concrete matrix. Further, higher heat of hydration, higher water content and high porosity increases the vulnerability of concrete mass when it is exposed to an extreme range of external and internal destructive environmental condition. This disturbs the soundness of the concrete and result in reduced durability of concrete structure. cement providing early high strength at the field. The high- grade cements have been enhancing by changing the ratio of Tricalcium silicate (C3S) to Dicalcium Silicate (C2S) and increasing the binding properties of the cement with due respect of time. These percentage changes of silicate have resulted in high early strength rather than high strength cement. It has been found out that structure constructed using high grade cement during 1945-50 have distress within span of 15 to 20 years. ***(Abdullah et. al. 2022)*** When the detailed analysis of concrete structure was carried out, it was revealed that

1. As the hydration of cement takes place gradually in the mix, lime is also liberated gradually. A small quantity of liberated lime in the concrete mix is used to main a in pH of the concrete mix and the major portion remains unused/ surplus and makes pores in concrete matrix.
2. The high-grade of cement releases higher amount of surplus lime resulting pores in concrete matrix.

Further, higher heat of hydration, higher water content and high porosity increases the vulnerability of concrete mass when it is exposed to an extreme range of external and internal destructive environmental condition. This disturbs the soundness of the concrete and result in reduced durability of concrete structure.

II. Literature

Branston et. al. (2022) has studied about Chopped glass fibre has recently gained popularity in concreter in forcing applications due to its environmentally friendly manufacturing process and excellent mechanical properties. The aim of this research is to evaluate the relative merit of two types of glass fibre (bundle dispersion fibres and mini bars) in enhancing the mechanical behaviour of concrete. Concrete specimens were cast with three different quantities of each fibre, and then evaluated based on flexural and drop-weight impact testing. Interfacial properties were also investigated by scanning electron microscopy. The results indicated both types of fiber increased pre-cracking strength, but only mini-bars enhanced the post- cracking behaviour, likely due to protection from the polymer.
High et.al. (2021) investigated the use of glass fiber bars as flexural reinforcement for concrete members and the use of chopped glass fibers as an additive to enhance the mechanical Properties of concrete. The material characteristics and development length of two commercially-available glass fibre bars were evaluated. Test results indicate that flexural design of concrete members reinforced with glass fibre bars should ensure compression failure and satisfying the serviceability requirements. ACI 440.1R-06 accurately predicts the flexural capacity of members reinforced with glass bars, but it significantly underestimates the deflection at service load level. Use of chopped glass fibres had little effect on the concrete compressive strength; however, significantly enhanced its flexural modulus.
Jiang et al. (2019) shows with high ductility and sufficient durability fiber reinforced concrete

(FRC) are widely used. In this study, the effects of the volume fraction and length of glass fiber (BF) on the mechanical properties of FRC were analyzed. Coupling with the scanning electron microscope (SEM) and mercury intrusion Potosí meter (MIP), the microstructure of BF concrete was studied also. The results show that adding BF significantly improves the tensile strength, flexural strength and toughness index, whereas the compressive strength shows no obvious increase .Furthermore, the length of BF presents an influence on the mechanical properties. Compared with the plain concrete, the compressive, splitting tensile and flexural strength of concrete reinforced with 12 mm BF increase by 0.18–4.68%, 14.08–24.34% and 6.30–9.58% respectively. As the BF length increasing to 22 mm, corresponding strengths increaseby0.55–5.72%, 14.96–25.51%and7.35–10.37%,
Separately. A good bond between the BF and the matrix interface is observed in the early age. However, this bond shows degradation to a certain extent at 28 days. Moreover, the MIP results indicate that the concrete containing BF presents higher porosity.

Ilker et al. (2018) adopted a numerical method for predicting the moment capacity of FRP concrete beams. Comparisons with experimental results show that the proposed numerical technique can accurately estimate moment capacity of RC beams reinforced with FRP bars. It was also noticed that the ACI-440.1R-06 formulae reasonably predicted the moment capacity of FRP reinforced concrete beams. Finally, it was shown that a large increase in FRP reinforcement produces a slight increase in the moment capacity of FRP over reinforced concrete beams. A parametric study concluded that concrete compressive strength has no effect on the moment capacity of FRP under reinforced concrete beams but a significant influence for the over reinforced equivalent.

Mohamed et al. (2017) studied the influence of fibers on the flexural behavior and ductility of GFRP reinforced concrete beams. Their tests showed that using GFRP as internal reinforcement for RC beams results in reasonable flexural strength. Furthermore, their results indicated that ACI 440.1R- 06 strongly underestimated the moment capacities of FRP RC beams.

Kassem et al. (2017) reported that the crack width in FRP reinforced concrete beams varied linearly with the applied moment up until failure. The crack width was smaller for the Beams with greater reinforcement ratios. Similarly, (Theriaul et al. 1998) noted that the residual crack width decreases as the reinforcement ratio increases. The beams reinforced with sand- coated bars exhibited a greater number of cracks as opposed to those reinforced with ribbed-surface bars. This suggests that the tested sand- coated bars provided a better bond with the concrete than the ribbed surface bars.

Masmoudi et al. (2014) tested a number of FRP reinforced concrete beams subjected to static loading. The beams were tested in order to investigate the effects of reinforcement ratio on ultimate capacities and modes of failure. They observed from this study that as the reinforcement ratio increases, the ultimate moment capacity increases, but that this increase is limited by the concrete compression failure strain for the reinforced concrete beams. The results from the flexural tests of concrete beams reinforced with FRP rebar’s indicated that the use of GFR Preparing concrete structures is possible and that optimal design is achievable if not only an appropriate reinforcement ratio is used, but also the appropriate height-to- span ratio is computed *(Benmokrane et al., 1995).* Other researchers, such as (*Habeeband Ashour 2008)* and (*Ashour and Habeeb 2008)*, noticed that over-reinforcing the bottom layer of either the simply or continuously supported GFRP beams is a key factor in enhancing the load capacity of concrete beams. Comparisons between the experimental results and those obtained from simplified methods proposed by the ACI440 Committee show that ACI 440.1R-06 equations can reasonably estimate the load capacity of GFRP reinforced concrete beams under test.

Masmoudi et al. (2010) concluded that the maximum observed crack width in beams reinforced with FRP reinforcing rods is 3 to 5 times that of identical beams reinforced with steel bars. It was also found that the residual crack width decreases as the reinforcement ratio increases; however, the results have shown that the residual crack width is not affected, after the first cycle of loading/unloading, by the number of loading/unloading cycles.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, No.1, May : 2024

III. OBJECTIVE OF THE STUDY

The main objective of this study is to evaluate the Compressive strength of concrete of grade M25 with addition of glass fibre in proportion of 0%, 1%, 2% and 3% by weight of cement.

IV. RESEARCH METHODOLOGY

4.1 Mix Design of Glass Fibre Reinforced Concrete

In this investigation, the preferred characteristic strength of 25 N/mm2 at 28 days was used. A method based on IS 456-2000and IS: 10262-2009 was used to create the blend. For this experiment, a total of 12 cubes, 36 beams, have been created. Every set was made with control mix with w/c=0.45. Compressive strength tests were performed on three samples from each batch of the mix at 7, 14, and 28 days of age. The amount of material (cement, fine aggregate and coarse aggregate) needed for every cubic meter of concrete is stated as the mix design. The mix design of plain concrete is carried out in accordance with the Indian Standard technique of mix design (as per IS: 456-2000, IS: 10262- 2009)

a) Design and testing information for the material
b) Concrete mix’s desired mean strength
c) Ratio of water to cement content
d) Water content calculation Cement content calculation
e) Determination of aggregate content, both coarse and fine

a) Design data and test data for material

Table 1: Design data (as per IS: 456-2000, IS: 10262-2009)

S.NO.	DESIGN DATA	DESIGNATION
1	Grade of Concrete	M-25
2	Type of Cement	OPCgrade-43
3	Maximum Cement content	450 kg/m^3
4	Minimum Cement content	300 kg/m^3
5	Maximum nominal size of Aggregate	20mm
6	Compaction factor	0.85to0.87
7	Workability	27 to75mm
8	Exposure condition	Mild

Table 2: Test data (as per IS: 1489-1991, IS: 2386-1963)

S.NO	DESIGN DATA	DESIGNATION
1	Specific gravity of cement	3.15
2	Specific gravity of water	1
3	Specific gravity of coarse aggregate	2.60
4	Specific gravity of fine aggregate	2.60
5	Water absorption of fine aggregate	1.0%
6	Water absorption of coarse aggregate	0.5%

b) Target means strength of concrete mix

$F_{ck}=f_{ck}+ t \times S$.

Where,

F_{ck}=Target average compressive strength at 28days f_{ck}= Characteristics compressive strength at 28 days

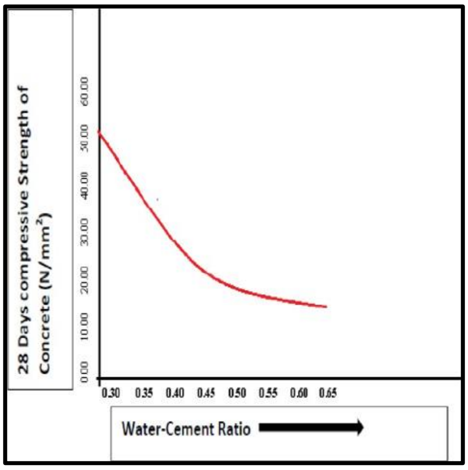
S=Standard deviation, and IS10262-2009 Table1

For a large number of tests, the value of "t" is static and depends on the accepted fraction of poor results.

$$F_{ck} = 25 + 1.65 \times 4 = 31.6\ N/mm^2$$

c) Ratio of water to cement content

Compressive strength at 28days vs. water cement ratio is presented on a graph to help choose the water content.



Graph 1: Water–cement ratio

According to the Graph water-cement ratio is=0.45

d) Water content calculation using table 2 and IS code IS: 456-2000

The 20 mm aggregate's maximum water content is 186 liters.

According to IS:383-1973's Table-4, fine aggregate absorbed 6% of its weight in water when it was saturated and dry.

e) Cement content determination

Cement content is equal to the product of water and cement. 191.7/0.45 is the cement content. 437.78 kg/m of cement are in the sample (according to IS code IS: 456-2000 from table-5)

Minimum cement content=300kg/m^3

$$450\ Kg/m^3 > 437.78\ Kg/m^3 > 300\ Kg/m^3$$

Hence ok

f) Determination of coarse and fine aggregate content

Aggregate can be determined by following equation: -

$V=[W+c/S_c+1/p \times (f_a/S_{fa})] \times (1/1000)$ (1)

$Ca= [(1-P/P) \times f_a \times (S_{ca}/S_{fa})]$ ……….(2)

Where:-

V=Absolute volume of fresh concrete V = (V1) – Volume of entrapped air

V=100%-2%[as per M. S. SHETTY from Table1. 23pg492] V = 98%

W=mass of water of concrete (kg/m^3) C = mass of cement (kg /m^3)

S_c=specific gravity of cement

P = ratio of fine aggregate to total aggregate by absolute volume (as per M. S. SHETTY pg496)

F_a C_a=total mass of fine aggregate and coarse aggregate Putting the value in equation (1)
Volume of fine Aggregate: -
$V=[W+c/S_c+1/p \times (f_a/S_{fa})] \times (1/1000)$
$0.98=[197+437.78/3.15+ 1/0.315 \times (f_a/2.60)] \times (1/1000)$
Putting the value in equation (2) Volume of Coarse Aggregate:

$Fa = 527.50 kg/m^3$

$C_a=[(1-P/P) \times f_a \times (S_{ca}/S_{fa})]$

$Ca = 1147.10 kg/m^3$

$C_a=[(1-0.315/0.315) \times 527.50 \times (2.60/2.60)]$

Table 3: The mix proportion of M-25 Grade concrete

Water (kg/m^3)	**Cement (kg/m^3)**	**Fine aggregate (kg/m^3)**	**Coarse aggregate (kg/m^3)**
191.76	437.78	527.50	1147.10
0.45	1	1.2	2.62

Table 4: Experimental Program

S. No	**Proportion for Beams**	**Proportion for Cubes**	**No. of Cube s**	**No. of Beams**
1	Plain Beams	Plain Cubes	3	9
2	1%GF	1%GF	3	9
3	2%GF	2%GF	3	9
4	3%GF	3%GF	3	9

4.2 MATERIALS USED

Following materials have been used in present work

1. Cement
2. Fine aggregate
3. Coarse aggregate
4. Water
5. Glass Fiber

4.2.1 CEMENT: - As a binding component in mortar and concrete, alumina, silica, lime, iron oxide, and magnesium oxide powder are burned together in a kiln and then finely ground. In this experimental effort, cement that complies with IS: 1489(Part 1)-1991 and comes in 43 grades is called Ultra Tech Ordinary Portland Cement. Tables 3.4 and 3.5 list the chemical and physical characteristics of ordinary Portland cement as determined by relevant tests carried out in accordance with IS: 269/4831and the specifications set forth in IS: 1489-1991

Table 5: Physical Properties ordinary Portland cement

S. No	Particulars	Test result
1	Specific gravity	3.15
2	Fineness(sieve analysis)	2.13%
3	Normal consistency	31%

Table 6: Chemical properties of Ordinary Portland cement

S. No.	Particulars	Proportion (%)
1	Calcium oxide (CaO)	59.98
2	Silicondi oxide (SiO2)	21.18
3	Aluminum oxide (Al2O3)	5.36
4	Iron oxide (Fe2O3)	3.48
5	Sulphur oxide (SO3)	2.8
6	Magnesium oxide (MgO)	2.05
7	Ignition loss (LOI)	2.67
8	Potassium oxide (K2O)	0.69
9	Sodium oxide (Na2O3)	0.36
10	Insoluble Residue	2.32
11	Free Lime	1.06

4.2.2 FINE AGGREGATE: - Another essential component of concrete that aids in the appropriate bonding of fine aggregate and cement is fine Aggregate. Sand is smaller than a 4.75mm sieve in size. Fine aggregate, as defined by IS:383 1963, is described as material that passes through a 4.75 mm IS sieve but is held on a 0.07 mm IS sieve. As a fine aggregate, river sand from the Narmada River that was locally accessible and had a size of less than 0.07 mm was employed

Table 7: Physical Properties

S. No	Properties	Results	Permission limit as per IS: 2386-1963
1	Type	Natural	-
2	Shape	Rounded	-
3	Size	>4.75µ	Retain on 0.07 mm
4	Organic impurities	Colorless	Colorless /Straw Color /Dark color
5	Silt content	1.85%	Should not be more than 6-10%
6	Specific gravity	2.60	-
7	Bulking of sand	7.52%	Should not be more than 40%
8	Bulk Density (Kg/m^3)	1570	-
9	Free moisture content	1.0%	-

4.2.3 COARSE AGGREGATE: - The primary component of concrete, which provides the structure its final strength, is aggregate. According to IS:383-1970, "coarse aggregate" is defined as "aggregate retained on 4.75mm IS sieve and containing only as much finer material as is permitted by. "The experimental work will use coarse aggregate in the 10mm and 20mm sizes.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, No.1, May : 2024

Table 8: Physical and Mechanical properties of Coarse aggregate (IS: 2386-1963)

S. No	Properties of material	Coarse aggregates	Permission limit as per IS: 2386-1963
1	Type	Crushed	-
2	Shape	Angular	-
3	Size	20mm&10 mm	-
4	Specific gravity	2.60	-
5	Fineness modulus	7.1	-
6	Bulk density(kg /m3)	1426	-
7	Impact value	15.60%	Should not be morethan30% used
9	Crushing value	14.58%	Should not be more than 30%used
10	Loss Angeles Abrasion Value	17.5%	-
11	Flakiness Index	20.57%	-

4.2.4 WATER: - It uses regular potable water that is devoid of salt, turbidity, and organic material. Water has been employed throughout the project's inquiry to mix the ingredients and cure them.

4.3 LABORATORY WORK

1. Proportioning
2. Batching and Mixing
3. Casting
4. Vibrating
5. Curing

4.4 COMPRESSIVE STRENGTH TEST PROCEDURE FOR GFRC CONCRETE CUBE

4.4.1 A Comprehensive Definition of Compressive Strength

The ability of a material or structure to support loads on its surface without cracking or bending under certain forces is known as compressive strength. A substance's size frequently changes when it is crushed, and it usually elongates when it is stretched

4.4.2 Compressive Strength and Resistance Calculation Formula

The formula for calculating a material's compressive strength is the load applied at the point of failure divided by the cross- sectional area of the face that was loaded. The load divided by the cross-sectional area of a material yields its compressive strength.

4.4.3 Measuring the Concrete Cubes' Compressive Strength

The cube test uses cubes that are either 10 centimeters by 10centimeters by 10 centimeters or 15 centimeters by 15 centimeters by 15 centimeters in size, depending on the size of the aggregate. For the majority of the works, cube moulds with dimensions of 15 centimeters on each side, 15 centimeters high and 15 centimeters deep are frequently utilized. This concrete is properly tempered before being placed in the mould to ensure that the final result is flawless. The test specimens are

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, No.1, May : 2024
then cured by being submerged in water after the moulds have been removed from them after twenty-four hours. These molded specimens should have a perfectly flat and smooth top surface These specimens are tested for strength utilizing compression testing machinery after either seven or twenty-eight days of cure. Until the specimen fails, a load should be added gradually at a rate of 140 kg/cm2 per minute. Continue doing this until the specimen fails. By dividing the weight that caused the specimen to fail by the area of the specimen, the compressive strength of concrete may be calculated

4.4.4 Concrete Cube Testing Procedure

The specimen should be taken out of the water and any extra moisture should be wiped away once the stipulated length of time has passed around the specimen's measurement to the closest 0.2 meters. Place the specimen into the testing device after cleaning the bearing surface, making sure the load is positioned on the opposite sides of the cast-iron cube. To proceed, the specimen must be set on the machine's base plate. The moveable part should be manually rotated until it touches the specimen's top surface. Apply the weight gradually, without shock, and continuously at a rate of 140 kg/cm^2/minute until the specimen collapses. Make sure to note the maximum load as well as any unexpected failure type characteristics

4.4.5 Compressive strength calculations

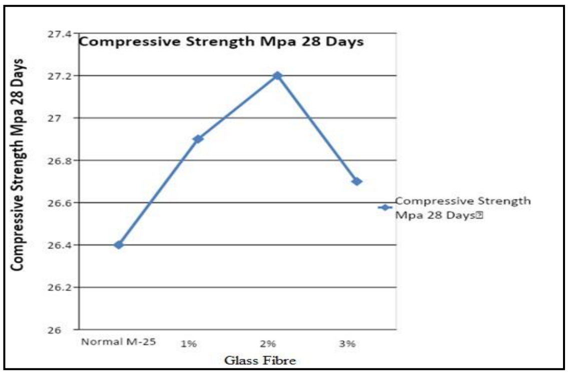
Dimensions of the cube are 15x15x15cm.
Calculated from the specimen's average size, the specimen's area is 225 cm^2.
Expected maximum load x Characteristic compressive strength (f_{ck}) at 7 days
= f_{ck} x area x fs

4.4.6 Compressive Strength

Total Twelve cubes were casted of Glass fiber of different percentage (0%, 1%, 2% and 3%). Three cubes were also casted with plain cement concrete. All the specimens were cured at 28 days. In present study average compressive strength of Glass fiber reinforced concrete is slightly increased up to 2% of glass fiber. The variation of compressive strength of GFRC of M25 concrete 7 days, 14days, 28days are soon in

Table 9: Compressive Strength of GFRC

Mix	**Compressive Strength MPa**		
	7 Days	**14 Days**	**28 Days**
NormalM-25	-	-	26.4
GlassFiber1%	-	-	26.9
GlassFiber2%	-	-	27.2
GlassFiber3%	-	-	26.7



Graph 2: Compressive Strength values at Different Percentage of GFRC

V. CONCLUSIONS

A detailed experimental study was performed to study the effect of addition of Glass fiber in different percentages by weight of cement in M25 grade concrete. This study was intended to find the effective ways to utilize the high impact Glass fiber as addition by weight of cement in concrete Analysis of the results of the effect of using Glass fiber as addition by weight of cement on the strength of concrete leads to the following conclusions-

- The incorporation of Glass fiber in concrete causes gradual decrease in workability.
- 24% decrease in workability is observed when the fiber content is 2% added.
- In this experimental study it has been found that the Compressive strength of GFRC increases gradually up to 2.0% and shows optimum result at 2.0% after that Compressive strength of GFRC decreases with increase of Glass fiber percentage.
- The increase of approx 1.0 % in Compressive strength is observed for GFRC (at 2% of fiber addition) in comparison to unreinforced sample.
- It is observed that failure of fiber reinforced concrete specimen do not show brittle failure. The progression of failure plane is gradual.

VI. REFFRENCES

Abdalla, H. 2011.“Evaluation of deflection in concrete members reinforced with fiber reinforced polymer FRP bars.” Compos.Struct.,56(1),63–71.

Achillides, Z., Pilakoutas, K. 2011, “Bond Behavior of Fiber Reinforced Polymer Bars under Direct Pull out Conditions”, ASCE Journal of Composites for Construction, Vol. 8, No. 2, March-April 2004.

ACI Committee 440. 2010. “State-of-the-Art Report on Fiber Reinforced Plastic FRP Reinforcement for Concrete Structures.” ACI440R-96, American Concrete Institute, Detroit, MI.ACI Committee 440. (2002) Recommended test methods for FRP rods and sheets. In: Unpublished draft specifications. Farming t on Hills, MI: American Concrete Institute.

Ahmed,EA.,El-Salakawy, E.and Benmokrane,B.(2006).“Performance Evaluation of Glass Fiber -Reinforced Polymer Shear Reinforcement for Concrete Beams.” ACI Structural Journal, 107(1),53-62.

BaenaM,TorresLl, Turon A, BarrisC.2009. “Experimental study of bond behavior between concrete and FRP bars using a pull-out test”Compos. Part B Eng., 40(8):784–97.

Barris, C., Torres, Ll.,Turon, A., Baena, M. & Catalan, A. 2009.An experimental study of the flexural behavior of

GFRP RC beams and comparison with prediction models. Composites Structures 91(09):286-295.

Benmokrane, B., Chaallal, O. and Mamoudi, R. (1996) . “Flexural Response of Concrete Beams Reinforced with FRP Reinforcing Bars.”ACI Structural Journal, 93(1), 46-55.

Benmokrane, B., El-Salakawy, E.F., Cherrak, Z., and Wiseman,A.(2004). “GFRP Composite Bars for the Structural Concrete Slabs of a PWGSC Parking Garage.” Canadian Journal of Civil Engineering,31(5),732-748.

Benmokrane, B., Ghao, D., and Tighiouart, B. (2010) . “Investigation on the bond of fiber reinforced polymer FRP rebar’s to concrete.” Proc., 2nd Int. Conf. on Compos. In Infrastructure, University of Arizona, Tucson.

Benmokrane, B.; Chaallal, O.; and Masmoudi, R. 1995, “Glass Fiber Reinforced Plastic (GFRP) Rebar’s for Concrete Structures”, Construction & Building Materials Journal, 9(6), pp.353–364.