

Effectiveness of Wrapping in Enhancing the Durability of Concrete Elements Subjected To Aggressive Environment

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ABSTRACT: This paper presents the experimental results of a study investigating the effectiveness of bond between fiber reinforced polymer (FRP) and concrete elements subjected to aggressive environments. Fiber reinforced polymer (FRP) have been widely used for retrofitting of concrete structures. Many researchers are focused on the use of FRP as an externally bonded strengthened system. The short term performance of FRP strengthened concrete structures has been intensively studied. However the performance of the externally strengthened concrete structures with FRP subjected to aggressive environments has been relatively less frequently studied till date. For more safety of the structural elements, we need to investigate more on the durability of concrete structure externally strengthened with FRP. This study presents performance of various FRP materials (CFRP, GFRP, AFRP and BFRP) as externally strengthened concrete structures and FRP concrete bond systems subjected to aggressive environments. The durability of FRP composite and FRP-concrete bond interface in immersion exposure will focus in this investigation.

KEYWORDS: Fiber reinforced polymer (FRP), Retrofitting, Externally bonded strengthened system, Aggressive environment, FRP-concrete bond interface.

I. INTRODUCTION

Reinforced Concrete (RC) structures have to face alteration and improvement of their performance over and over again during their service life. The main causative factors are change in their use, cracking and deterioration due to corrosion in the steel caused by exposure to an aggressive environment and damage resulting from natural disasters such as earthquakes. The promising solutions for these problematic causes are either replacement or retrofitting. Full structure replacement might have determinate drawback in terms of cost. So, it is better to repair the structure by means of retrofitting techniques. The rehabilitation of concrete structures is one of the most critical problems in area of the civil engineering applications.

The use of FRP materials in civil infrastructure for the repairing and strengthening of RC structures and also for new construction has become common practice. One of the techniques used to retrofit the existing RC elements is by external bonding of steel plates. FRP can be more suitable as compared to steel plate for many reasons. The advantages of FRP include their high strength and stiffness, light weight, and good resistance to fatigue and corrosion. FRP can be easily installed and are easy to cut at any length on site. The epoxy adhesives are used to bond the FRP composites to the surface of the concrete structure.

II. LITERATURE REVIEW

J.R. Cromwell, et al., presents the results of an extensive study investigating the performance of fiber reinforced polymer (FRP) materials and FRP bond to concrete when subjected to various environmental conditioning regimes. An extensive experimental program investigated the behaviour of three FRP systems subjected to nine different environmental conditioning protocols. The effect of environmental conditioning was assessed using four different standard test methods.

S. Cabral-Fonseca, et al., investigated durability issues associated with the structural bond between FRP and concrete for rehabilitation purposes. A number of factors determining the durability of FRP-concrete bonded joints

have been identified and grouped into the following categories: materials – adhesive and adherents, joint characteristics and in-service conditions. For each of those factors, the main findings obtained in previous studies are summarized and the aspects that need further investigation are outlined.

III. NECESSITY AND OBJECTIVE OF PRESENT STUDY

The use of FRP composites in civil engineering and construction is more recent. Strengthening of concrete structures by externally bonded FRP system now used routinely around the world and their effectiveness is well recognized. However, the long-term behaviour of FRP composites under service conditions still remains a crucial issue. The durability of FRP composite and FRP concrete bond interface in immersion exposure will focus in this study. The objective of this study is to determine and compare the durability characteristics (various chemical attack tests) of the retrofitted concrete elements subjected to aggressive environments.

IV. METHODOLOGY

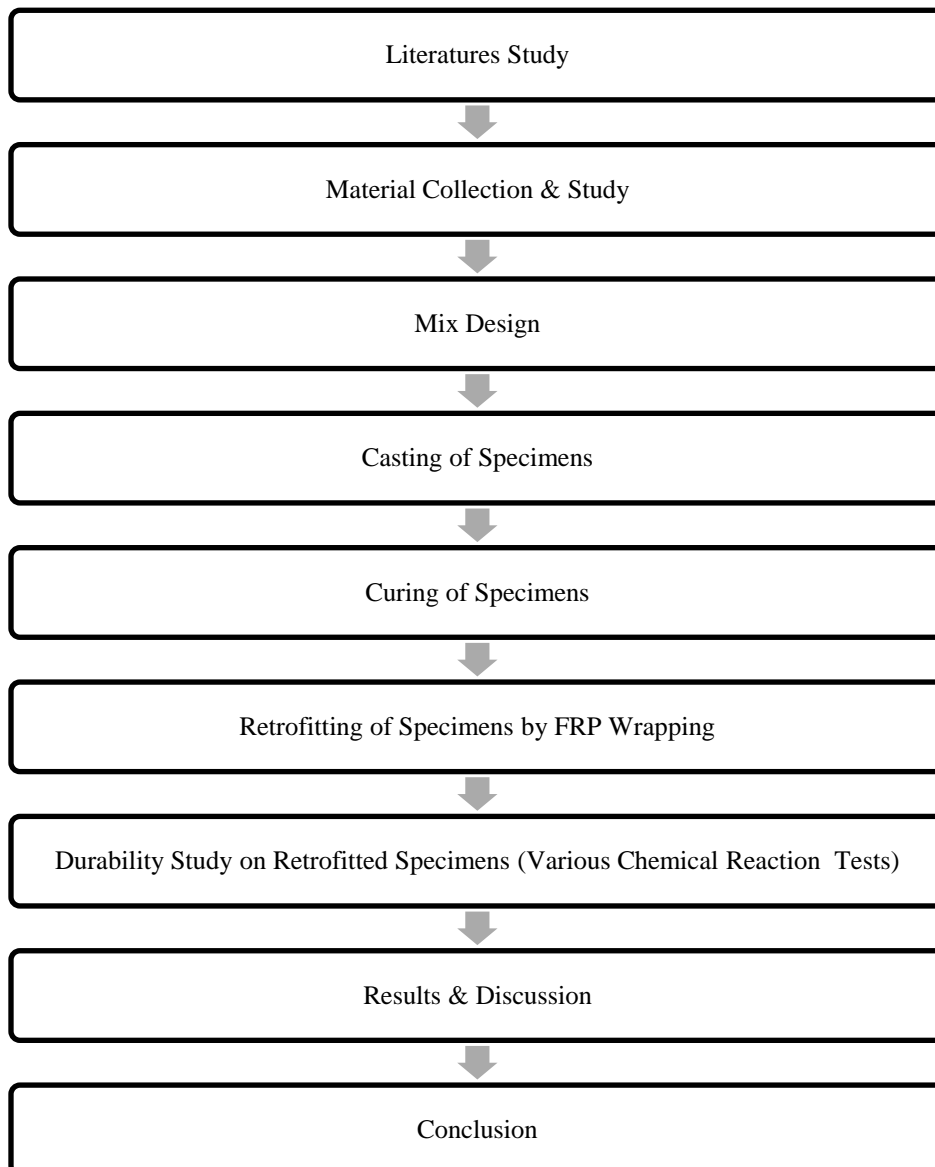


Figure 4.1 Methodology

V. EXPERIMENTAL INVESTIGATION

Materials used and Its Properties

The materials such as cement, fine aggregate, coarse aggregate, fibre reinforced polymer (FRP) are used in the present work. The materials used and their properties are showed below.

Cement

Ordinary Portland Cement (OPC) available in local market was used in this investigation. OPC 43 grade conforming with IS: 12269 - 1987 is used.

Table. 5.1 Properties of cement

Physical properties	Test results	Confirmation code
Specific Gravity	3.125	IS : 4031 – 1988 Permissible range 3.1 – 3.15
Percentage of fineness (%)	2	IS : 12269 - 1987 Shall not be more than 10
Specific Surface m ² /Kg	320	IS : 4031 - 1988 Shall not be less than 225
Setting Time (Minutes)		IS : 12269 - 1987
(a) Initial	30	Shall not less than 30
(b) Final	360	Shall not more than 600

Fine Aggregate

The locally available M-sand was used in this investigation as fine aggregate. The fine aggregate is tested for its physical properties like Specific Gravity, Fineness Modulus, Bulk Density in accordance with IS : 2386 (Part 3) – 1963.

Table 5.2 Properties of Fine Aggregate

Physical properties	Values obtained
Specific gravity	2.69
Fineness modulus	2.60
Bulk density kg/m ³	1702

Coarse Aggregate

Crushed angular granite stone was used in this investigation as coarse aggregate conforming to IS: 383 - 1970. The coarse aggregate is tested for its physical properties like Specific Gravity, Fineness Modulus, Bulk Density in accordance with IS : 2386 (Part 3) – 1963.

Table 5.3 Properties of Coarse Aggregate

Physical Property	Value Obtained
Specific Gravity	2.72
Fineness Modulus	6.9
Bulk Density kg/m ³	1538



Carbon Fibre Reinforced Polymer (CFRP)

Carbon fibre reinforced polymer is an extremely strong and light fiber reinforced plastic which contains carbon fibers.

Table 5.4 Properties of CFRP

Properties	Range
Fiber volume	65-70
Thickness (mm)	1.2-1.9
Tensile strength (MPa)	2690-2800
Tensile modulus (GPa)	155-160

Glass Fibre Reinforced Polymer (GFRP)

A Glass fiber-reinforced polymer (GFRP) composite was most commonly used in the manufacture of composite materials. The matrix comprised organic, polyester, thermostable, vinylester, phenolic and epoxy resins.

Table 5.5 Properties of GFRP

Properties	Range
Fiber volume	65-70
Thickness (mm)	1.4-1.9
Tensile strength (MPa)	900
Tensile modulus (GPa)	41

Aramid fiber reinforced polymer (AFRP)

Table 5.6 Properties of AFRP

Properties	Range
Fiber volume	70
Thickness (mm)	1.27
Tensile strength (MPa)	1400
Tensile modulus (GPa)	60

Basalt Fiber Reinforced Polymer (BFRP)

Basalt fiber is a relative newcomer to fiber reinforced polymers (FRPs) and structural composites. It has a similar chemical composition as glass fiber but has better strength characteristics.

Table 5.7 Properties of BFRP

Properties	Range
Fiber volume	70
Thickness (mm)	1.27
Tensile strength (MPa)	1400
Tensile modulus (GPa)	60

Experimental Program

Concrete mix proportion of M30 was calculated as per the design guidelines of IS: 10262 - 2009. The concrete mix ratio consists of 434 kg/m³ of OPC, 639 kg/m³ of fine aggregate, 1072 kg/m³ of coarse aggregate with water cement ratio of 0.45 for the test specimens used. The cylinders were wrapped fully with Carbon, Glass, aramid and basalt fiber reinforced polymers. The experimental program comprised of testing of a total number of 45 cylindrical specimens having diameter of 100 mm and 200 mm height. For rapid chloride penetration test a total number of 15 disc specimens having diameter of 100 mm and 50 mm height. All the specimens were wrapped and immersed to various exposure

conditions. All the immersed specimens were subjected to axial compressive load after 90 days of immersion. The details of specimens are tabulated below.

Table 5.8 Details of specimens

Exposure condition	Wrapping material	Type of wrapping	No of samples
Acid exposure	CFRP, GFRP, AFRP, BFRP	Full wrapping	15 (3 each)
Alkaline exposure	CFRP, GFRP, AFRP, BFRP	Full wrapping	15 (3 each)
Sulphate exposure	CFRP, GFRP, AFRP, BFRP	Full wrapping	15 (3 each)



Figure 5.1 Casting of specimens

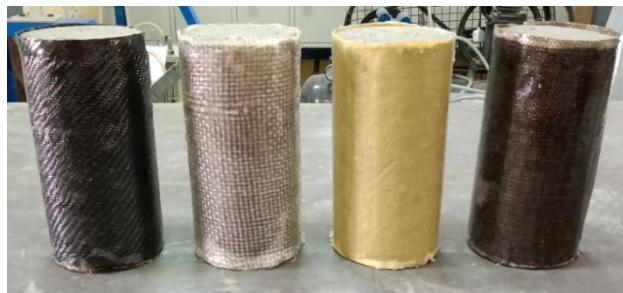


Figure 5.2 Retrofitted specimens

VI. RESULTS AND DISCUSSION

Based on the experimental investigation a detailed durability studies has been conducted for tensile strength test, bonding strength test and various chemical reaction tests like Acid attack test, Alkaline attack test, Sulphate attack test.

Acid Attack Test

Table 6.1 Compressive strength after acid attack test

Specimens	Controlled specimens	After immersion	% loss of compressive strength	Effectiveness of wrapping in %
	Avg compressive strength in MPa	Avg compressive strength in MPa		
Control	24.82	21.74	12.41	-
CFRP	27	25.44	5.78	53.42
GFRP	21.73	19.53	10.12	18.45
AFRP	24.92	23.28	6.58	46.98
BFRP	23.96	22.06	7.93	36.10

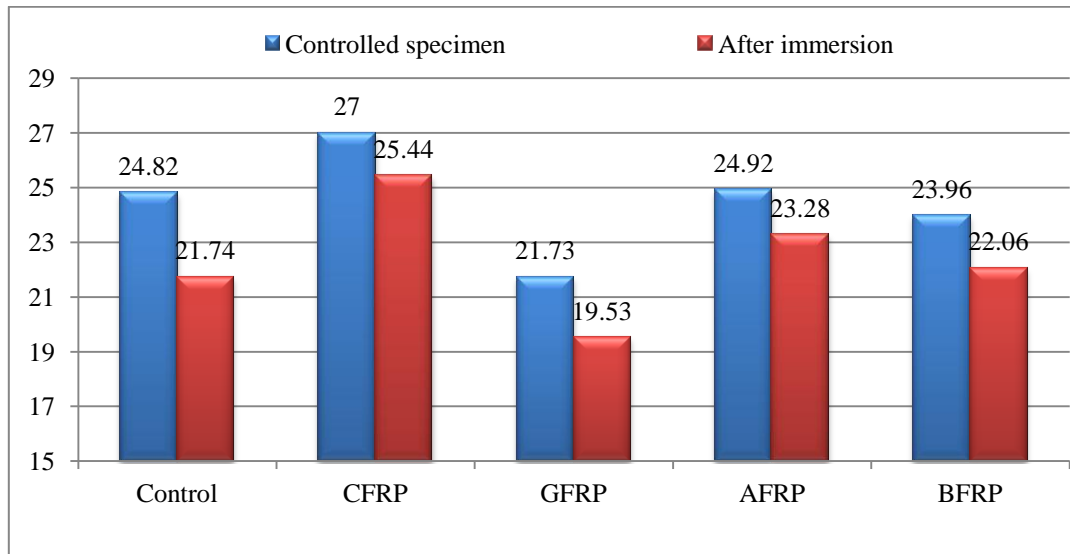


Figure 6.1 Comparison of compressive strength

Fig 6.1 showed that the compressive strengths of various FRP strengthened concrete elements after immersion to acid exposure for 90 days. The loss percentage in compressive strength (Fig 6.2) was 12.41% in control concrete after the acid exposure condition. But loss in compressive strength was minimized about 5.78% for CFRP wrapped concrete elements. Similarly 10.12%, 6.58 % and 7.93% for GFRP, AFRP and BFRP wrapped concrete elements respectively. This behaviour indicates that the effectiveness of wrapping (Fig 6.3) with FRP was enhanced by 53.42%, 18.45%, 46.98% and 36.10% for CFRP, GFRP, AFRP and BFRP respectively. From this investigation, we noticed that CFRP and AFRP were more effective than others in acid exposure condition.

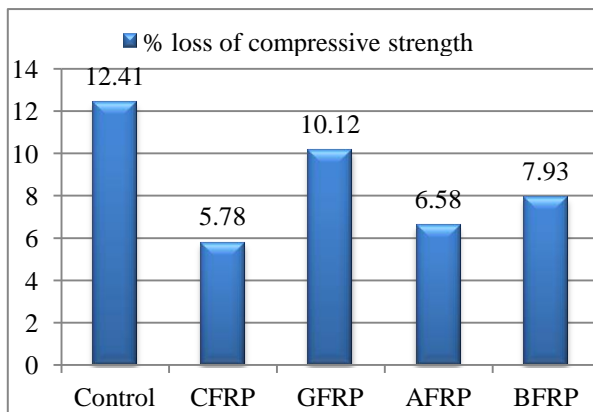


Figure 6.2 % loss of compressive strength

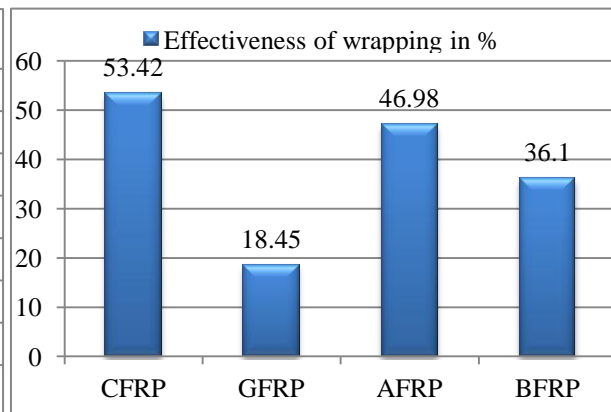


Figure 6.3 Effectiveness of wrapping

Alkaline Attack Test

Table 6.2 Compressive strength after alkaline attack test

Specimens	Controlled specimens	After immersion	% loss of compressive strength	Effectiveness of wrapping in %
	Avg compressive strength in MPa	Avg compressive strength in MPa		
Control	24.82	21.24	14.42	-
CFRP	27	25.32	6.22	56.87
GFRP	21.73	19.18	11.73	18.65
AFRP	24.92	22.93	7.99	44.59
BFRP	23.96	21.52	10.18	29.40

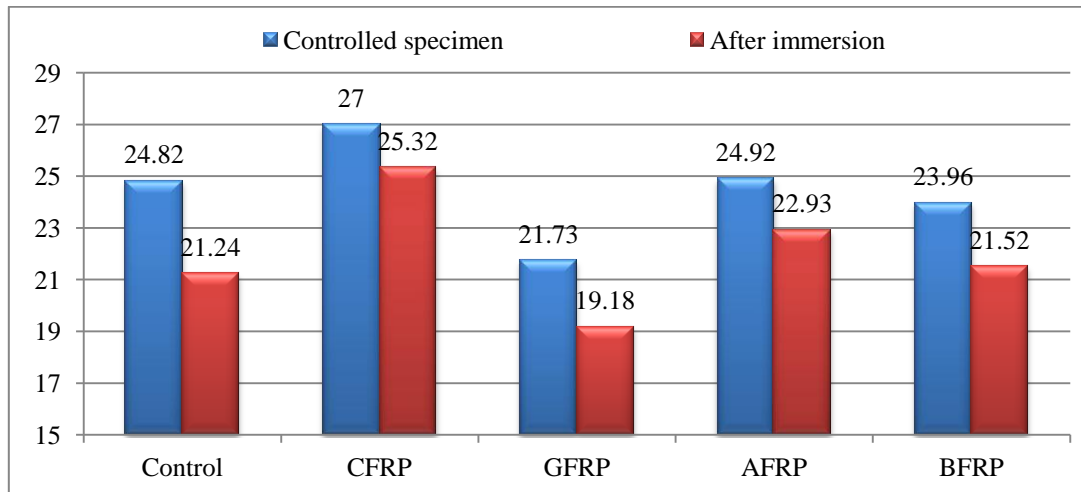


Figure 6.4 Comparison of compressive strength

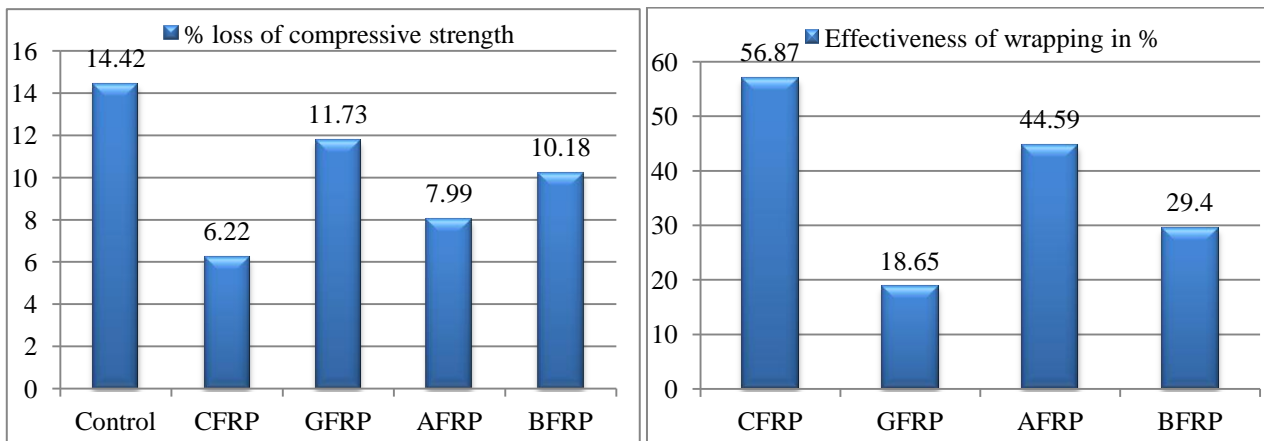


Figure 6.5 % loss of compressive strength

Figure 6.6 Effectiveness of wrapping in %

Fig 6.4 showed that the compressive strengths of various FRP strengthened concrete elements after immersion to acid exposure for 90 days. The loss percentage in compressive strength (Fig 6.5) was 14.42% in control concrete after the alkaline exposure condition. But loss in compressive strength was minimized about 6.22% for CFRP wrapped concrete elements. Similarly 11.73%, 7.99 % and 10.18% for GFRP, AFRP and BFRP wrapped concrete elements respectively. This behaviour indicates that the effectiveness of wrapping (Fig 6.6) with FRP was enhanced by 56.86%, 18.65%, 44.59% and 29.40% for CFRP, GFRP, AFRP and BFRP respectively. From this investigation, we noticed that CFRP and AFRP were more effective than others in alkaline exposure condition.

Sulphate Attack Test

Table 6.2 Compressive strength after sulphate attack test

Specimens	Controlled specimens	After immersion	% loss of compressive strength	Effectiveness of wrapping in %
	Avg compressive strength in MPa	Avg compressive strength in MPa		
Control	24.82	22.26	10.31	-
CFRP	27	25.12	6.96	32.49
GFRP	21.73	19.65	9.57	7.18
AFRP	24.92	23.16	7.06	31.52
BFRP	23.96	21.98	8.26	19.88

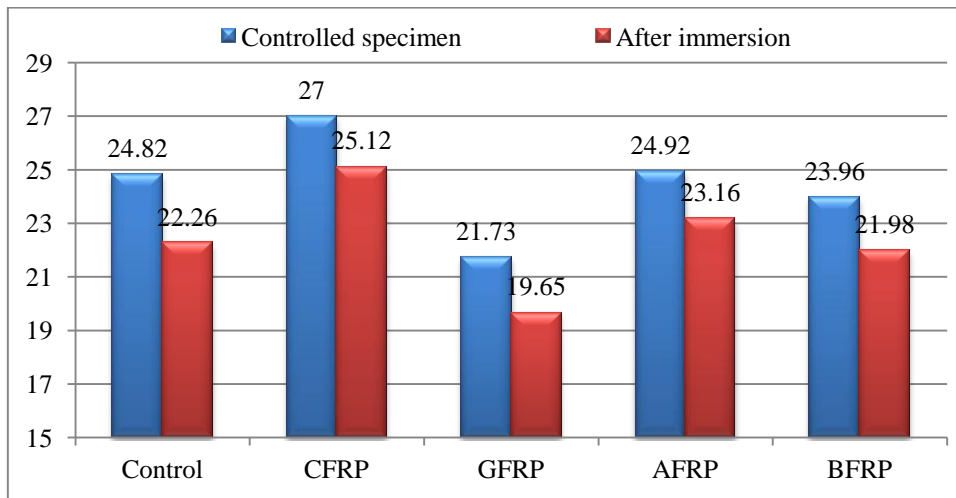


Figure 6.7 Comparison of compressive strength

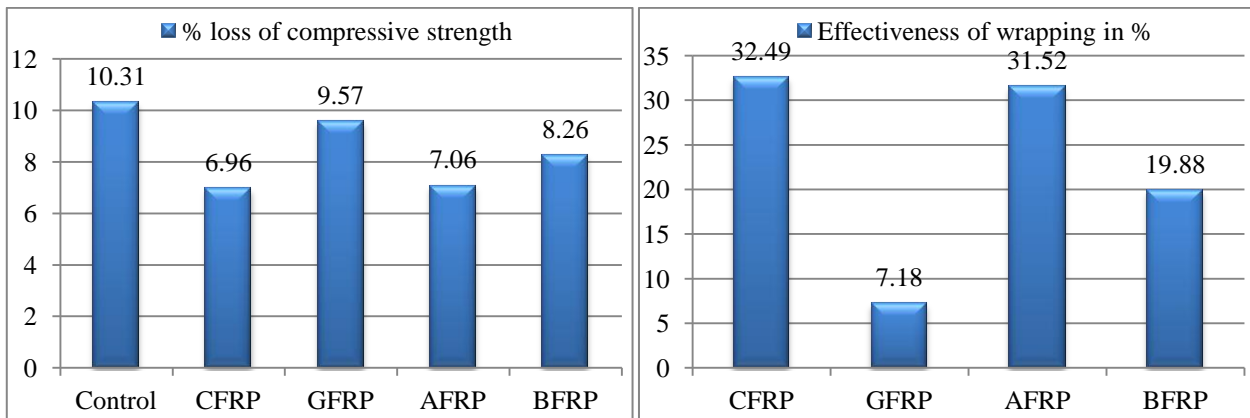


Figure 6.8 % loss of compressive strength

Figure 6.9 Effectiveness of wrapping in %

Fig 6.7 showed that the compressive strengths of various FRP strengthened concrete elements after immersion to sulphate exposure for 90 days. The loss percentage in compressive strength (Fig 6.8) was 10.31% in control concrete after the sulphate exposure condition. But loss in compressive strength was minimized about nearly 7% for both CFRP and AFRP wrapped concrete elements. Similarly 9.57 % and 8.26% for GFRP and BFRP wrapped concrete elements respectively. This behaviour indicates that the effectiveness of wrapping (Fig 6.9) with FRP was enhanced by 32.49%, 7.18%, 31.52% and 19.88% for CFRP, GFRP, AFRP and BFRP respectively. From this investigation, we noticed that CFRP and AFRP were more effective than others in alkaline exposure condition.

VII. CONCLUSION

Durability tests were performed to determine the effectiveness of FRP as strengthening material in aggressive environments. The compressive strength was slightly decreased after exposure condition in all cases. But percentage loss in compressive strength after aggressive exposure was minimized by FRP strengthening system. Which means effectiveness of wrapping was enhanced by 30-50% in aggressive environments due to FRP strengthening system. CFRP and AFRP were performed more effective than other FRPs.

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