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Effect of Glass Fiber Reinforced Polymer Wrapping on Strength of Confined Concrete

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Abstract— External wrapping with Fiber Reinforced Polymers (FRP) has been increasing in recent years for strengthening and retrofitting of concrete and steel structures. Hence an attempt has been made to investigate the compressive and tensile behavior of concrete specimens (cylinders) strengthened with GFRP. The parameters varied in this investigation were number of wraps (single and double wrapping) and curing period (wrapping after 7 and 28 days of water curing). The experimental result shows that the specimens wrapped with glass fiber reinforced polymers have higher compressive strength and tensile strength than the control specimens. For durability studies cylinders were immersed in acid solution (5 % H_2SO_4) for the period of 28 days. It was noticed that the damage due to acid attack was severe in control specimen than the wrapped cylinders.

Keywords— Glass fiber reinforced polymer (GFRP), Confined concrete, Compressive strength, Acid attack. Scanning electron microscope (SEM)

I. INTRODUCTION

Continuous fiber-reinforced materials with polymeric matrix (FRP) can be considered as composite, heterogeneous, and anisotropic materials with a prevalent linear elastic behaviour up to failure. They are widely used for strengthening of civil structures. There are many advantages of using FRPs: lightweight, good mechanical properties, corrosion-resistant, etc. Composites for structural strengthening are available in several geometries from laminates used for strengthening of members with regular surface to bi- directional fabrics easily adaptable to the shape of the member to be strengthened. Composites are also suitable for applications where the aesthetic of the original structures needs to be preserved (buildings of historic or artistic interest) or where strengthening with traditional techniques cannot be effectively employed.

FRP composite is a two-phased material, hence its anisotropic properties. It is composed of fiber and matrix, which are bonded at interface. Each of these different phases has to perform its required function based on mechanical properties, so that the composite system performs satisfactorily as a whole. In this case, the reinforcing fiber provides FRP composite with strength and stiffness, while the matrix gives rigidity and environmental protection.

Carbon fiber and glass fiber are two materials suitable for strengthening concrete structures. Over the past two decades, Carbon Fiber Reinforced Polymer (CFRP) has been increasingly used in strengthening and retrofitting RC structural members. The use of CFRP provides a cost-effective solution in strengthening structural elements. The CFRP strengthened section gains double the strength, with a moderate increase in stiffness (about 10%). On the other hand, Glass Fiber Reinforced Polymer (GFRP) provides less stiffness and has lower cost than CFRP, which makes it a better alternative.

II. MATERIALS USED AND THEIR PROPERTIES

Cement, fine aggregates, coarse aggregates, water and admixture are used in casting of concrete cylinders. GFRP sheets and epoxy resin are used as the retrofitting material. The specifications and properties of these materials are as under:

A. Cement: Ordinary Portland cement of grade 53 make from a single lot is used for the study. The physical properties of cement as obtained from various tests are listed in Table 1. All the tests are carried out in accordance with procedure laid down in IS 1489 (Part 1):1991, valid for ordinary portland cements.

Sr. No.	Characteristics	Test Value	Value specified by IS :1489-1991 (Part 1)
1.	Standard Consistency (%)	32	---
2.	Soundness (mm)	0.86	Max 10 mm
3.	Fineness of cement as retained on 90 micron sieve (%)	8 %	---
4.	Setting time (mints) 1.Initial 2.Final	 120 210	 Min 30 (min) Max 600 (min)
5.	Specific gravity	3.15	

Table 1 Physical Properties of Ordinary Portland Cement

B. Fine Aggregates: Locally available sand is used as fine aggregates in the preparation of the concrete mix. The physical properties of sand are shown in Table 2.

Table 2 Physical Properties of Fine Aggregates

Sr. No.	Characteristics	Value
1.	Specific gravity (oven dry basis)	2.644
2.	Fineness modulus	3.35
3.	Water absorption	0.54 %
4.	Grading Zone (Based on percentage passing 600 µm sieve)	Zone III

C. Coarse Aggregates: Crushed stone aggregates (locally available) of 20 mm and 10 mm are used through-out the experimental study. The physical properties of coarse aggregates is given in Table 3.

Table 3 Physical Properties of Coarse Aggregates

Sr. No.	Characteristics	Value	
		CA - I	CA - II
1.	Type	Crushed	Crushed
2.	Maximum nominal size (mm)	20 mm	10 mm
3.	Specific gravity	2.93	2.847
4.	Total water absorption	1 %	1.12 %
5.	Fineness modulus	7.67	5.97

D. Water: Fresh and clean water is used for casting and curing the specimens. The water is relatively free from organic matter, silt, oil, sugar, chloride and acidic material as per requirements of Indian standard.

E. Admixture: Master Rheobuild 822 is used as a admixture in concrete mix design. Master Rheobuild 822 is a ready-to-use liquid which is dispensed into the concrete together with the mixing water.

F. GFRP Sheets: Unidirectional glass fiber was used as the retrofitting material. This fiber is commercially available and comes in a 1.37x45.72 m roll. The manufacture reports a tensile strength and elastic modulus of 3240 MPa and 72.4 GPa, respectively.

G. Epoxy- Resin: Thermax maxtreat epoxy-resin was used as a control in this study. This particular resin is commercially produced to be used with glass-fiber fabric. The epoxy-resin consists of two-parts: maxtreat saturant hardner and maxtreat saturant resin. The tensile strength and elastic modulus of this resin based on manufacturer specifications are 72.4 MPa and 3.18 GPa, respectively.

III. EXPERIMENTAL PROGRAMME

A. Mix Design (M-30): Concrete mix design for M-30 grade concrete is prepared as per IS 10262: 2009

Table 4 Concrete Mix Design for M-30 Grade Concrete (As per IS)

Cement	400 kg
F.A. (39%)	714 kg
CA - I (40%)	811 kg
CA – II (21%)	414 kg
Water	177.3 lit
Admixture (0.8%)	3.2 kg
Ratio	1 : 1.78 : 3.06
W/C Ratio	0.44

B. Specimen preparation and curing:

Casting and testing of specimen was carried out as per IS:516-1959 for compression strength and split tensile strength. Materials are weigh batched, mixed in a mixer, cast into steel moulds and specimens were stored in room temperature for 24 hours, then removed from the moulds, and cured in normal water for 7 and 28 days.

C. Testing:

Cylinders of size 150 mm diameter and 300 mm length were tested to compute compressive strength and split tensile strength of concrete. Specimens were tested under the compression testing machine of 3000 kN capacity. Total 36 specimens are tested in compression testing machine. Three control specimens, three with single layer of GFRP and three with double layer of GFRP are tested after 7 days and 28 days of curing of the specimens.

D. Durability test:

The acid attack test was conducted by immersing the specimens in the acid water for 28 days after 28 days of curing. Sulfuric acid (H_2SO_4) with pH of about 0.1 at 5% weight of water was added to water in which the specimens were stored. The pH was maintained throughout the period of 28 days. After 28 days of immersion, specimens were taken out of acid water. Then, the specimens were tested for compressive strength. Total 18 specimens are tested in compression testing machine. Three control specimens, three with single layer of GFRP and three with double layer of GFRP are tested after 7 days and 28 days of acid attack of the specimens.

E. SEM Analysis:

A scanning electron microscope (SEM) is done to examine deteriorated concrete due to acid attack.

IV. RESULTS AND DISCUSSION

A. Mechanical properties:

The test results of compressive strength and split tensile strength for confined and unconfined specimens are tabulated.

1) Compressive strength:

Confined and unconfined specimens of size 150mm dia. and 300mm height were tested for compressive strength. Compressive strength test results are shown in table 5 and fig 1. The compressive strength result shows that there is an increase in compressive strength of GFRP wrapped specimen compare to the control specimen. The highest compressive strength of 59.80 MPa is obtained at 28 days for GFRP double wrapped specimen. There is 78.98% increase in strength of double wrapped specimen compare to the control specimen. Compressive strength of single wrapped specimen is less compare to double wrapped specimen. There is 43.66% increase in strength of single wrapped specimen compare to the control specimen.

Table 5 Compressive strength test

Sr. No.	Specimen description	Compressive strength (MPa)	
		7 days	28 days
1.	Control specimen	23.9	33.41
2.	Specimen wrapped with 1 layer GFRP	36.41	48.0
3.	Specimen wrapped with 2 layer GFRP	51.19	59.80

Table 6 Percentage increase in compressive strength

Layers of GFRP	Compressive strength (MPa)	Percentage increase in strength
Control specimen	33.41	--
Single layer	48.0	43.66
Double layer	59.80	78.98

Fig. 1 Compressive strength test (a) control specimen (b) GFRP wrapped specimen

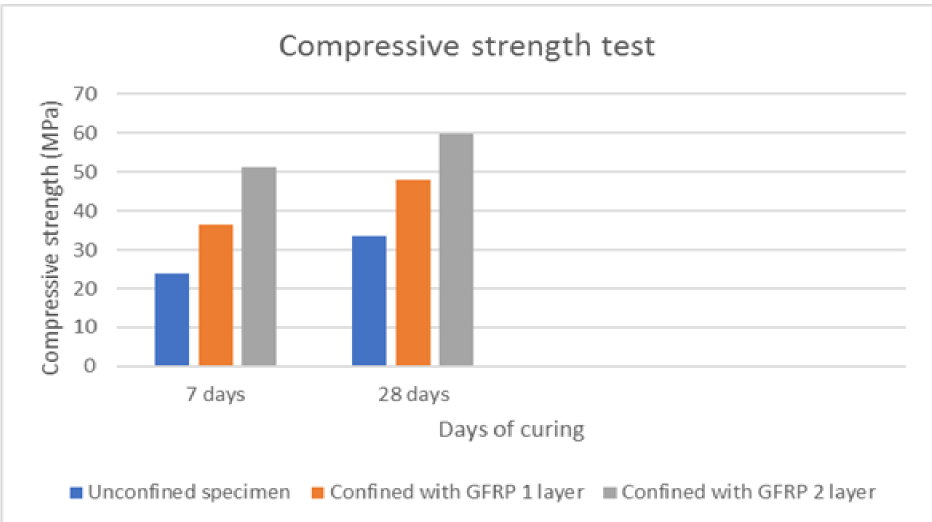

Fig. 2 Compressive strength

2) Split tensile strength:

Confined and unconfined specimens of size 150mm dia. and 300mm height were tested for split tensile strength. Split tensile strength test results are shown in table 7 and fig 4. The split tensile strength result shows that there is an increase in tensile strength of GFRP wrapped specimen compare to the control specimen. The highest tensile strength of 4.25 MPa is obtained at 28 days for GFRP double wrapped specimen. There is 57.99% increase in strength of double wrapped specimen compare to the control specimen. Tensile strength of single wrapped specimen is less compare to double wrapped specimen. There is 28.99% increase in strength of single wrapped specimen compare to the control specimen.

Table 7 Split tensile strength test

Sr. No.	Specimen description	Tensile strength (MPa)	
		7 days	28 days
1.	Control specimen	2.27	2.69
2.	Specimen wrapped with 1 layer GFRP	3.02	3.47
3.	Specimen wrapped with 2 layer GFRP	3.54	4.25

Table 8 Percentage increase in tensile strength

Layers of GFRP	Compressive strength (MPa)	Percentage increase in strength
Control specimen	33.41	--
Single layer	48.0	43.66
Double layer	59.80	78.98

Fig. 3 Split tensile strength test (a) control specimen (b) GFRP wrapped specimen

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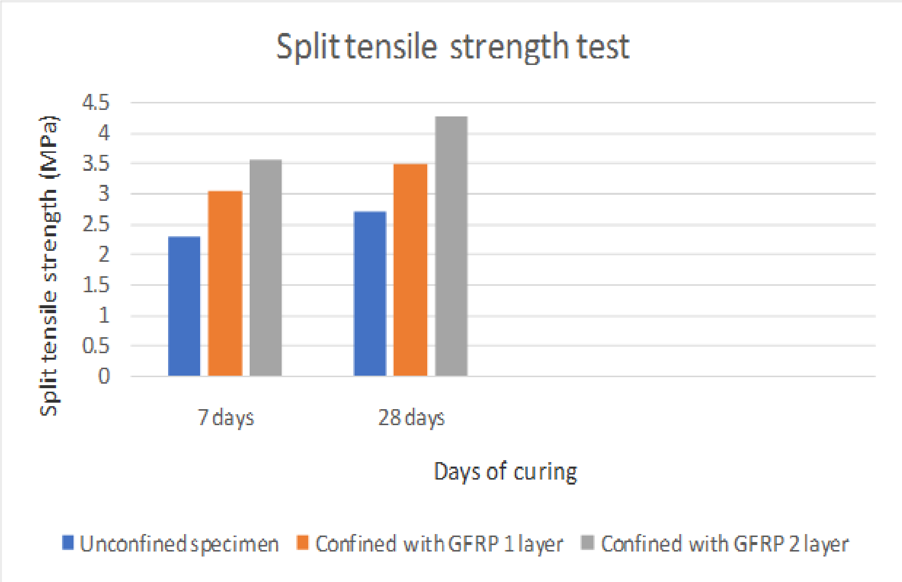

Fig 4 Split tensile strength

B. Durability test:

After acid immersion for 28 days, weight loss and the strength loss of the confined and unconfined specimens were determined using compressive strength machine. Results show that, the control specimens deteriorated more and the loss of strength was higher compared to the GFRP wrapped specimens. In a way, the GFRP acted as a shield for the concrete. There is 47.44% loss of compressive strength in control specimens after acid attack, while it is only 9.03% in GFRP double wrapped specimens. In brief, the durability of the GFRP wrapped specimens was better than the control specimens.

Table 9 Loss of weight and compressive strength after 28 days of acid attack

Sr. No.	Description	Weight after 28 days of water curing (kg)	Weight after 28 days of acid attack (kg)	% loss of weight	Compressive strength after 28 days of water curing (MPa)	Compressive strength after 28 days of acid attack (MPa)	% loss of compressive strength
1.	Control specimen	13.13	11.68	11.27	33.41	17.56	47.44
2.	Specimen wrapped with 1 layer GFRP	13.92	13.87	0.35	48	40.83	14.93
3.	Specimen wrapped with 2 layer GFRP	13.90	13.88	0.14	59.80	54.40	9.03

Fig. 5 Acid attack test (a) control specimen (b) GFRP wrapped specimen

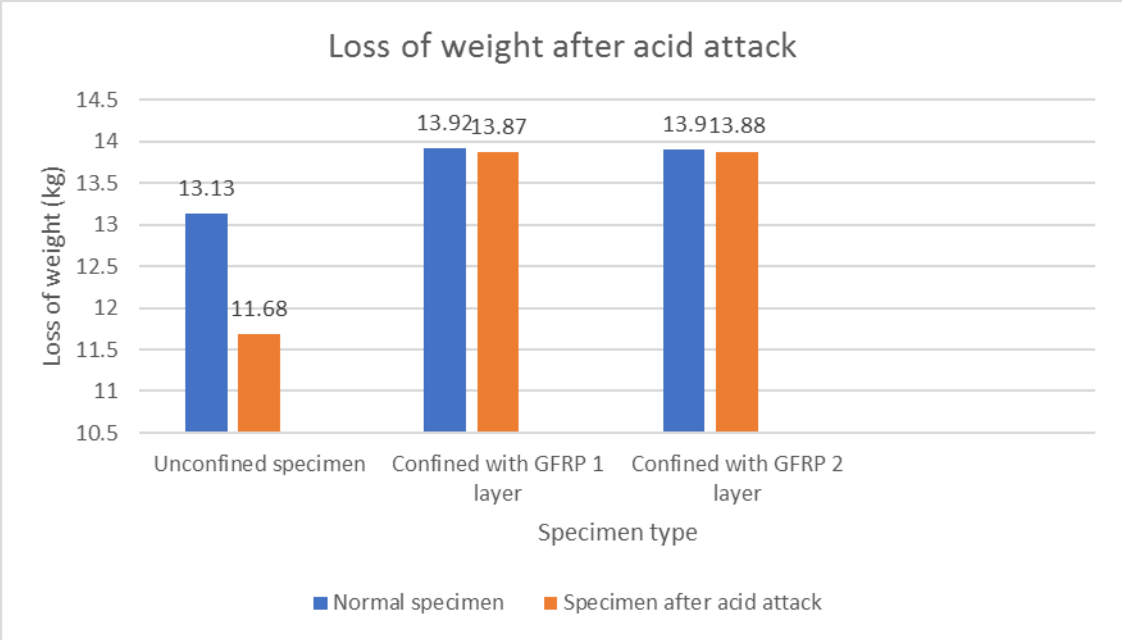

Fig. 6 Loss of weight after acid attack

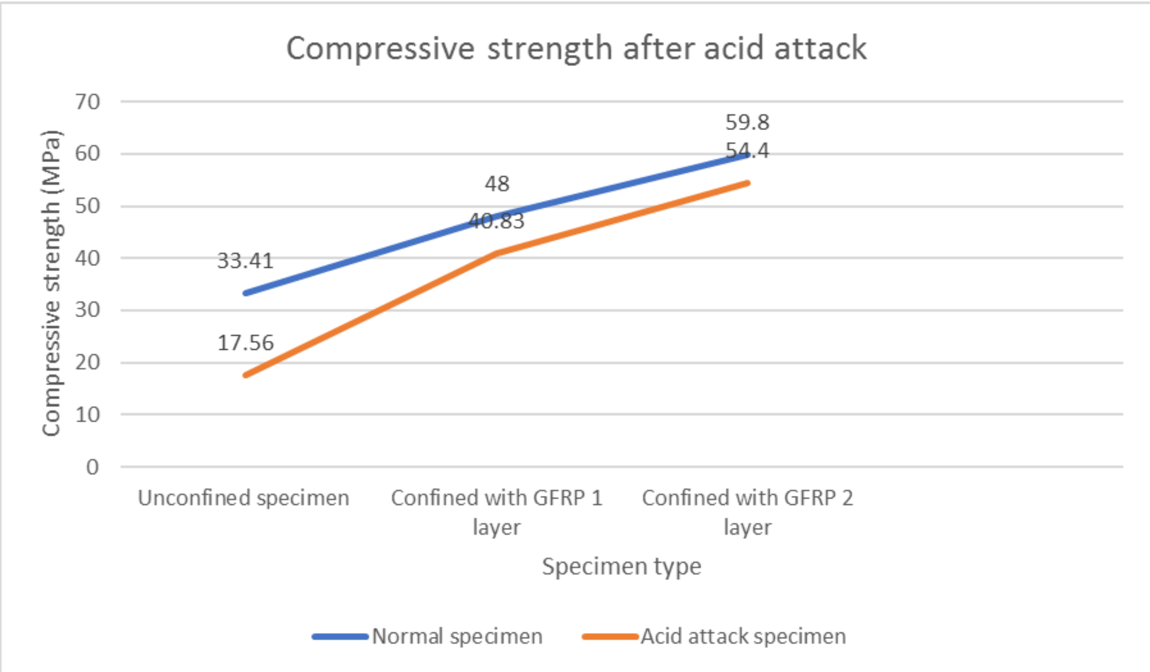

Fig. 7 Compressive strength after acid attack

C. SEM analysis:

The microstructural images of unconfined and confined with GFRP specimens after acid exposure, are compared in Figures 8 and 9. As seen in Figures 8(b) and 9(b), the GFRP wrapped concrete looks sound. The images in Figures 8(a) and 9(a) show that after acid attack the unconfined concrete looks soft. This explains the visual observation that the outer layer of confined concretes still had a stable shape after being neutralised by sulphuric acid.

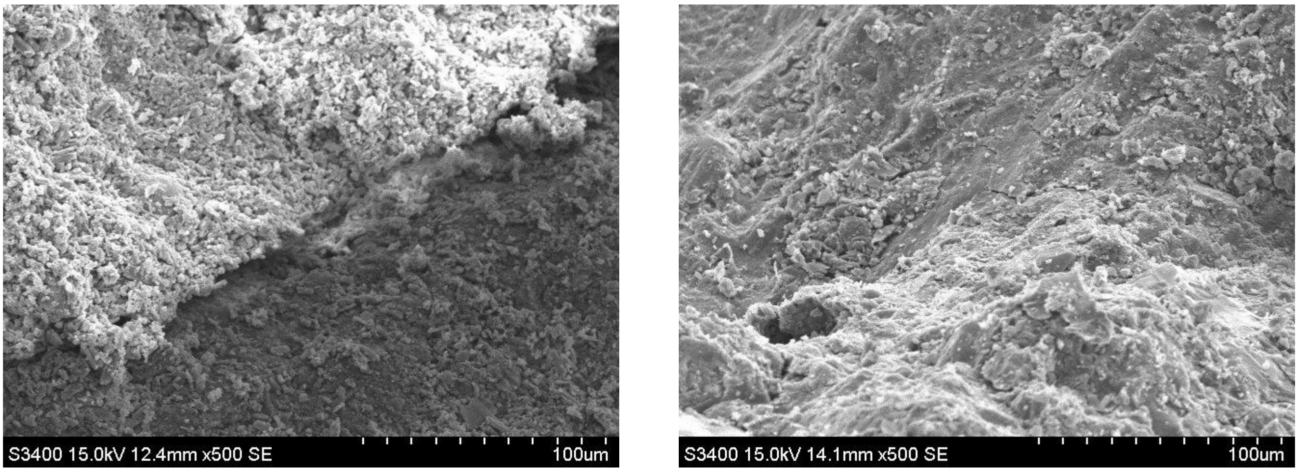

Fig. 8 SEM images of acid attacked specimen at 500x magnification (a) Unconfined (b) Confined

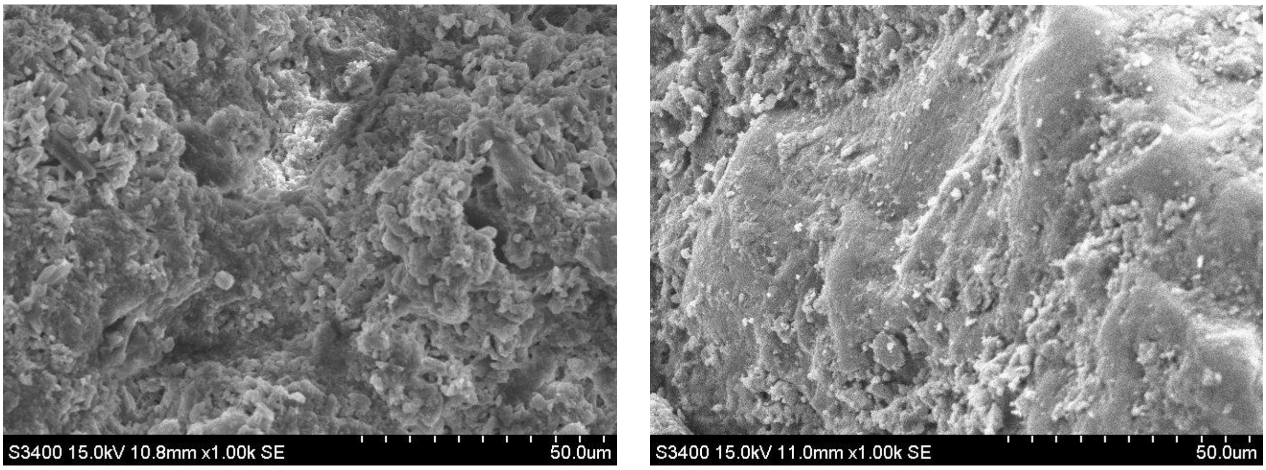

Fig. 9 SEM images of acid attacked specimen at 1000x magnification (a) Unconfined (b) Confined

V. CONCLUSION

In this paper, the effect of GFRP confinement on mechanical properties were experimentally studied and also performed durability test and SEM analysis. Then, based on experimental results following conclusions can be highlighted:

1) The compressive strength of specimens doubly wrapped with glass fibers has shown an increase by about 78.98% over the compressive strength of control specimens. While, The compressive strength of specimens singly wrapped with glass fibers has shown an increase by about 43.66% over the compressive strength of control specimens.
2) The split tensile strength of specimens doubly wrapped with glass fibers has shown an increase by about 57.99% over the split tensile strength of control specimens. The split tensile strength of specimens singly wrapped with glass fibers has shown an increase by about 28.99% over the split tensile strength of control specimens.
3) The strength of the specimens wrapped with GFRP materials are greatly improved compared to the unconfined concrete cylinders. Thus, it can be concluded that glass fiber can be used as a strengthening material for concrete specimens.
4) The durability studies on specimens with acidic exposure conditions were studied. It was noticed that due to the acidic exposure, the deterioration in the control specimen was high than the GFRP wrapped specimens.
5) The weight loss of control cylinders on acidic exposure was higher than the GFRP wrapped cylinders. This was due to more loss on the core concrete due to acid.

6) Similarly, the strength reduction for acidic exposure condition was 47.44% for the control concrete specimens. There was a sudden failure in control specimen. The effect of GFRP wrap minimized the strength degradation as compared to the control specimen.
7) Photomicrographs, clearly show that deterioration of concrete due to sulfuric acid attack starts at the surface and progresses inwards. SEM images show that deterioration of concrete due to sulfuric acid attack is more in control specimen compare to GFRP wrapped specimen.

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