Chemical attack and Sorptivity Characteristics of GFRC under different Curing Conditions

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Abstract

This paper identifies the effect of Acid, Alkali and Salt attack on Glass fiber concrete and Normal concrete under different types of curing conditions. Normal curing, Polythene sheet membrane curing and Calcium chloride integral curing were used for this experiment. The period of exposure of these chemicals are 30, 60 and 90 days. The chemicals that are used for the experiments include Sulfuric acid (H_2SO_4), Sodium Chloride (NaCl) and Sodium Sulfate (Na_2SO_4). Concrete cubes were immersed in solutions containing these chemicals for different exposure periods and the strength loss were determined. The optimum percentage of alkali resistant glass fiber used for this experiment is 3%. Sorptivity of the GFRC under different curing conditions were also determined. Sorptivity analysis identifies amount of water absorbed through capillary rise in concrete. The usage of GFRC in the construction increases the durability characteristics when compared with that of ordinary concrete. The effect of these chemical attacks varies in accordance with the curing types. In this study, Glass fiber reinforced concrete showed better chemical durability than the normal concrete. Acid attack caused the maximum strength and weight loss when compared to alkali and salt attack. Higher capillary rise was observed in the case of normal concrete under calcium chloride integral curing.

Keywords: Fiber reinforced concrete; Calcium chloride integral curing; Membrane curing; Acid attack; Salt attack; Sulfate attack; Sorptivity

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1. Introduction

The current world offers different environment to the concrete buildings. The pollution and the natural conditions lead to different chemical attacks in the concrete. The usage of concrete in industrial buildings leads to many chemical attacks. The buildings near to the seawater environment also experiences the same problem. The inclusion of glass fibers in the concrete not only increases its strength characteristics but also affect the durability characteristics. The presence of acid, alkali and chlorides in the atmosphere affects the concrete adversely. Their presence leads to deterioration of the buildings. These chemicals leads to strength loss which in turn affects the end use of the buildings. Presence of Alkali resistant glass fibers improves the chemical durability of the concrete [12]. It makes the buildings less affected by the chemicals and hence not affecting its end use. The curing conditions also plays an important role in the resistance to these attacks. Presence of saline environment near to the buildings will lead to chloride attack in the buildings [13]. Different additives in the concrete can improves it chemical durability. The presence of carbonated fly ash improves the chemical durability of the concrete against the acidic and sulfate environment, and the weight loss under chemical attack in fly ash concrete is much less when compared to the normal concrete [18]. Leaching of concrete is one of the major problem while the concrete surface is exposed to acids [11]. Sulfuric acid is one of the most dangerous acid to the concrete surfaces, as it triggers acid attack as well as sulfate attack

[14]. Capillary action in concrete results in the movement of water inside. The study of capillary action enables to understand the absorption characteristics of the concrete. . Proper curing will results in increased density and reduction in porosity. Pores, shrinkage, strength defects and chemical defects are the results of improper curing [4]. It is also proved that concrete will gain only 50% of its estimated strength when it is left uncured [3]. In this study 2% of Calcium chloride is added to the mix in order to enhance the early strength and thus accelerating the curing procedure. In the case of membrane curing, white polythene sheets are used for the curing.

2. Materials and Methods

2.1 Cement

Ordinary Portland cement is used for mixing. Testing of physical properties was in accordance with IS: 4031 and the results are tabulated in Table 1.

Table 1: Properties of Cement

Property	**Result**	**IS 12269-1987 requirements**
Specific Gravity	3.12	-
Fineness a) Blaine b) Sieve Test	275 m^2/Kg 2.5%	Min 225 m^2/Kg Not more than 10%
Standard Consistency	27%	-
Setting Time (Initial)	45 min	Not less than 30 min
Final Setting Time (Final)	360 min	Maximum 600 min
Le- Chatlier Soundness	2 mm	Not more than 10 mm

2.2. Fine Aggregate

River sand is used as the fine aggregate. Figure 1 depicts the particle distribution graph. The fineness modulus and the specific gravity of fine aggregate used was 3.83 and 2.68 respectively.

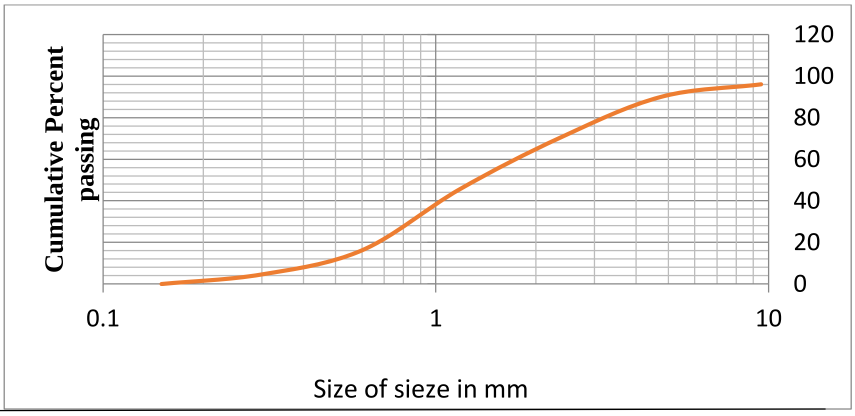

Figure 1: Particle Size Distribution graph for fine aggregate

2.3 Coarse Aggregate

Aggregates with nominal Size 20 mm was used. Water absorption and Specific Gravity was found to be 0.5% and 2.72 respectively. Figure 2 below represents the Particle Distribution graph for the coarse aggregate.

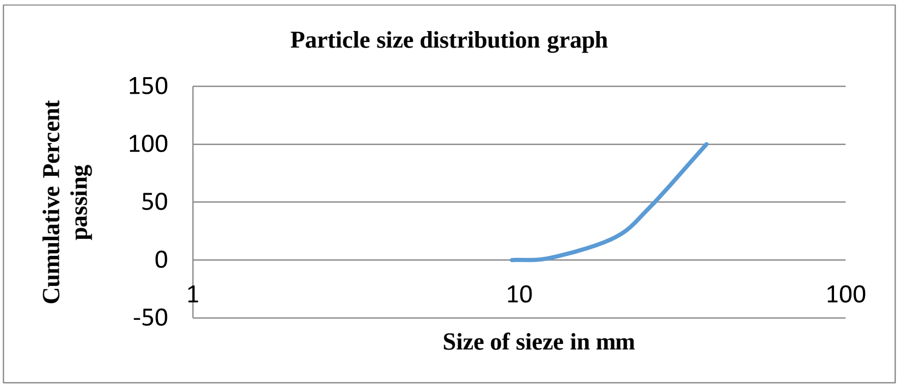

Figure 2: Particle Size Distribution graph for coarse aggregate

2.4. Mix Ratio

Mix ratio of M-30 concrete were calculated using IS: 10262-2009 and SP23, which resulted in a mix ratio of 1: 1.88: 3.38: 0.45 (Cement:Sand:Coarse aggregate:water cement ratio).

2.5. Calcium chloride

The CaCl properties that is used for the experiment is shown below

- Type : Powder
- Colour : White
- Odor : No Odor
- Solubility : Water Soluble

2.6 Glass Fiber

Table 2 shows the Glass fiber properties.

Table 2: Glass Fiber Properties

Property	**Result**
Type	Alkali Resistant
Specific Gravity	2.68
Elastic Modulus	72 GPa
Tensile Strength Length	2100 MPa
	12 mm
Density	2680 Kg/m^3
Aspect Ratio	857.1

2.7. Compression Strength Test

The compression test on the concrete cubes of size 15 cm were carried out as per IS: 516 - 1959.

2.8 Tensile Strength Test

150 mm diameter and 300 mm height cylindrical specimens were casted and tested as per IS: 5816.

2.9 Chemical Exposure

The test specimens were exposed to three types of chemical exposures. In the case of Acid exposure, the specimens were immersed in 5% H_2SO_4 solution. 5% of Na_2SO_4 and 5% of NaCl were used for alkali attack and salt attack respectively. The exposure period for specimens were 30, 60 and 90 days.

2.10 Sorptivity

Sorptivity (S) is the measure of capillary rise in the concrete. It is obtained by measuring the increase in the weight of the concrete, when one of the concrete surface is exposed to the water.

Time is considered as one of the major function in this test. The water absorption of the material is observed to be increasing as the square root of the immersing time (t). The procedure is as follows

a) Cylindrical Concrete specimen of 100mm diameter and 50mm height are prepared
b) The specimens are then water cured for a period of 60 days.
c) Specimens are then taken out and dried in an oven at 100 degree Celsius and the dry weight of the specimen was taken (W1)
d) Except the bottom side, the peripheral sides of the specimens are sealed by a non-absorbent coating.
e) The specimens are then kept in water so that the water level is not more than 5mm above the base of the specimen.
f) The specimen is immersed in water for a time period of 30 minutes and the water is quickly wiped off using a dry cloth and the weight is measured (W2).

The cumulative water absorption (I) increases as the square root of the immersing time (t).

$$I = S.\, t^{1/2}$$

Where, S= Sorptivity in mm,

t= Immersing time in minutes

$$I= \frac{\Delta W}{A*d}$$

ΔW= W2-W1

A= Surface area of the water penetrating surface of the specimen

d= Density of water

Therefore, Sorptivity, $S = I/(t^{1/2})$

3. Results and Discussions

3.1 Strength Characteristics and Chemical Exposure

The compressive strength and tensile strength after 28 days of different types of curing before the chemical exposure period are shown in Figure 3 and Figure 4 respectively. The compressive strength of both normal concrete and GFRC after 30, 60 and 90 days of exposure in Salt solution (NaCl), Sulfate solution (Na_2SO_4) and Acid Solution (H_2SO_4) after normal curing, membrane curing and calcium chloride integral curing are shown by the histograms in Figures 5-10. The percentage loss of strength and weight for normal concrete and GFRC for normal curing, polythene membrane curing and calcium chloride integral curing conditions under different chemical attacks for different exposure periods (30,60 and 90 days) are depicted in Figures 11-13 and Figures 14-16 respectively.

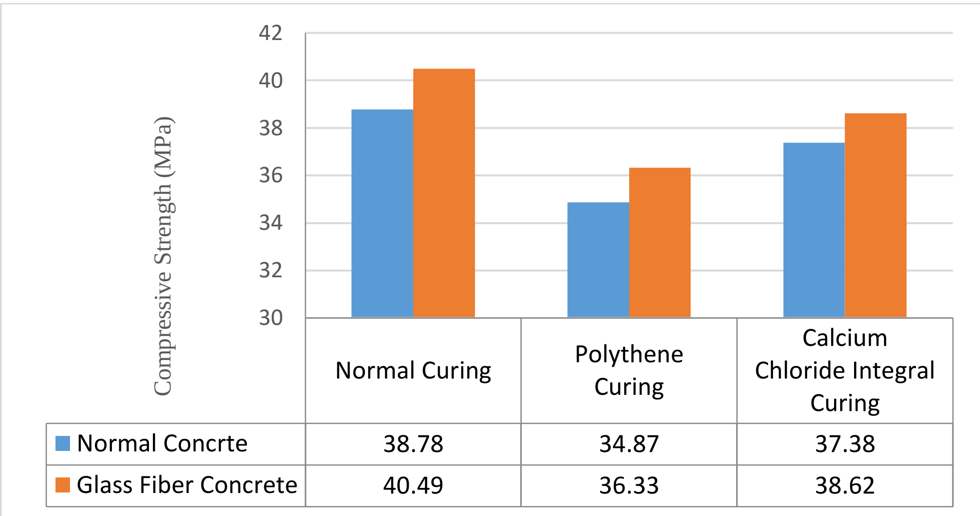

Figure 3: Compression Test result of Normal concrete and GFRC after 28 days of curing

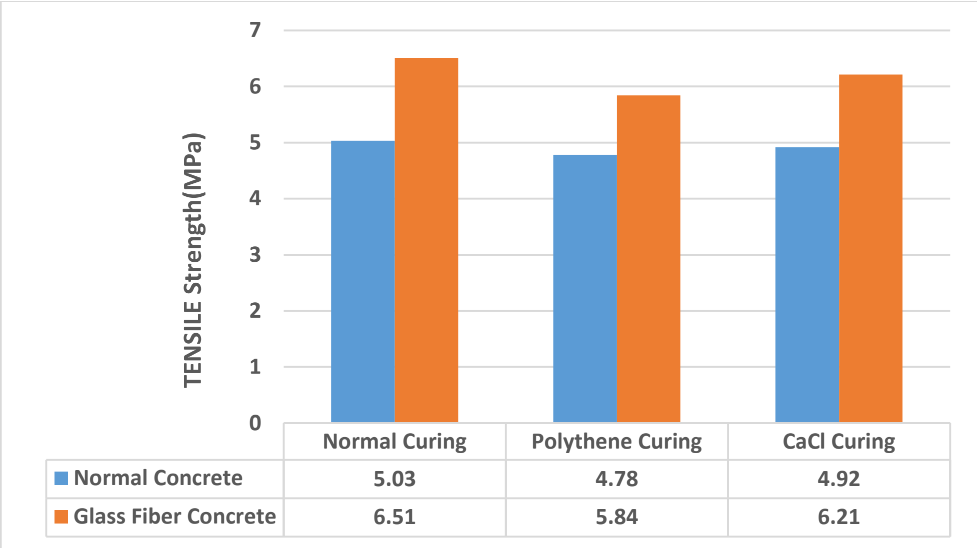

Figure 4: Tensile Test result of Normal concrete and GFRC after 28 days of curing

Strength loss due to Salt attack

In the case of normal curing, when both normal concrete and GFRC were immersed in 5% solution of NaCl, normal concrete showed the maximum strength loss for the three exposure periods. As the exposure period increases the compressive strength also reduced drastically. In the case of normal curing, the percentage of strength loss for normal concrete and GFRC were 8.01% and 6.06% respectively for chemical exposure period of 30 days. For the exposure period of 90 days, the percentage strength loss were observed to be 17.79% and 14.18% respectively for normal concrete and GFRC respectively. A similar trend was observed in the case of polythene membrane curing and calcium chloride integral curing. Normal concrete under calcium chloride integral curing resulted in the highest strength loss (19.96%) after a chemical exposure period of 90 days. In the case of tensile strength, strength loss percentages for normal concrete after 90 days of salt exposure resulted in 11.28%, 13.08% and 16.77% under normal curing, polythene curing and calcium chloride integral curing respectively. In the case of Glass fiber concrete, the percentages of strength loss were found to be 10.45%, 12.35% and 15.29% respectively for normal curing, polythene curing and calcium chloride integral curing under 90 days of salt exposure.

From the above observations, it is obvious that calcium chloride integral curing suffered the highest strength loss. Presence of calcium chloride at the time of mixing itself resulted in chlorite attack during the initial curing period. And the exposure to salt solution again caused the salt attack. The presence of salt lowers the PH in concrete leading to acidic reaction and in creating porous structure. It weakens the concrete and increases the pore size. Hygroscopic nature of salt retains the water in pores and leads to spalling. The chloride ions that are present in the pores react with the hydration products such as Calcium Silicate Hydrate (C-S-H), Calcium Hydroxide (C-H), Ettringite, Mono sulfate and Mono carbonate which results in Decalcification of concrete and leaching. The reinforcement present in the concrete will be affected by the corrosion as the chloride ions react with the iron forming iron hydroxide and hydrochloric acid.

$$Fe^{++} + 2\,Cl^{-} \longrightarrow FeCl_2$$

$$FeCl_2 + 2.\,H_2O \longrightarrow Fe(OH)_2 + 2HCl$$

The inclusion of glass fibers in the concrete resulted in reducing the porous structures and hence the strength loss was less when compared with that of the normal control concrete.

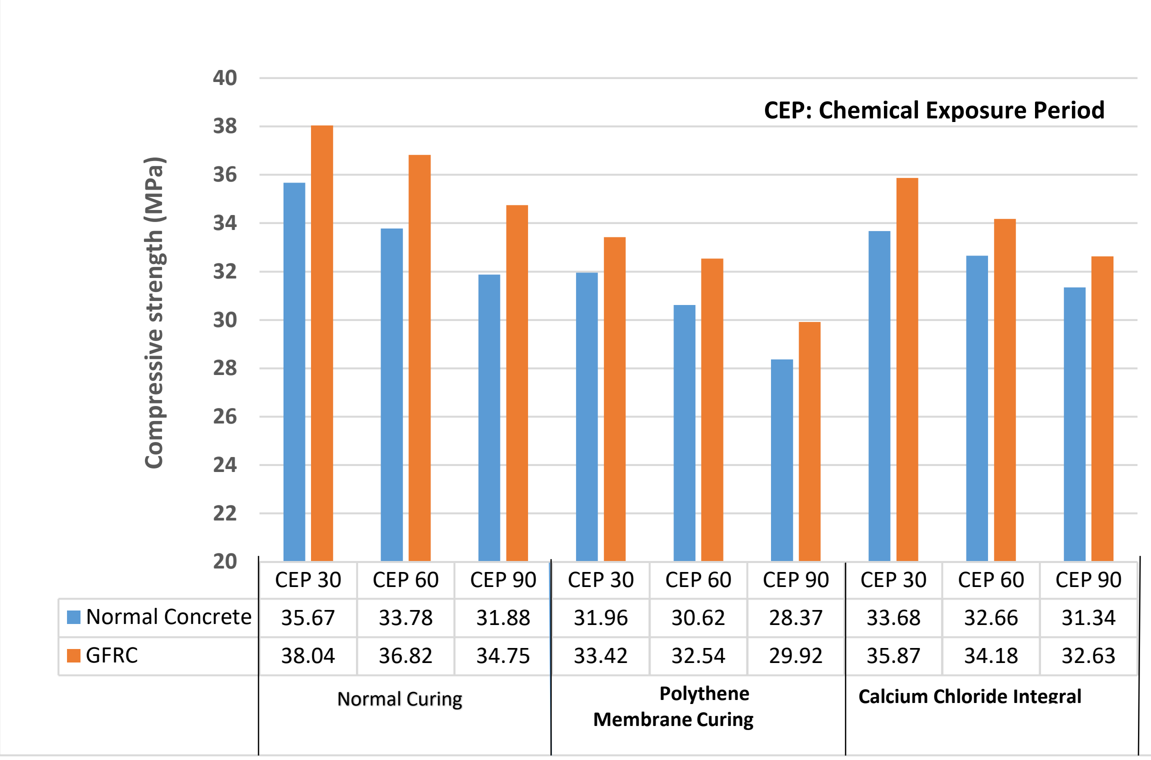

Figure 5: Comp. Strength after 30, 60 and 90 days of exposure of NaCl(5%) solution

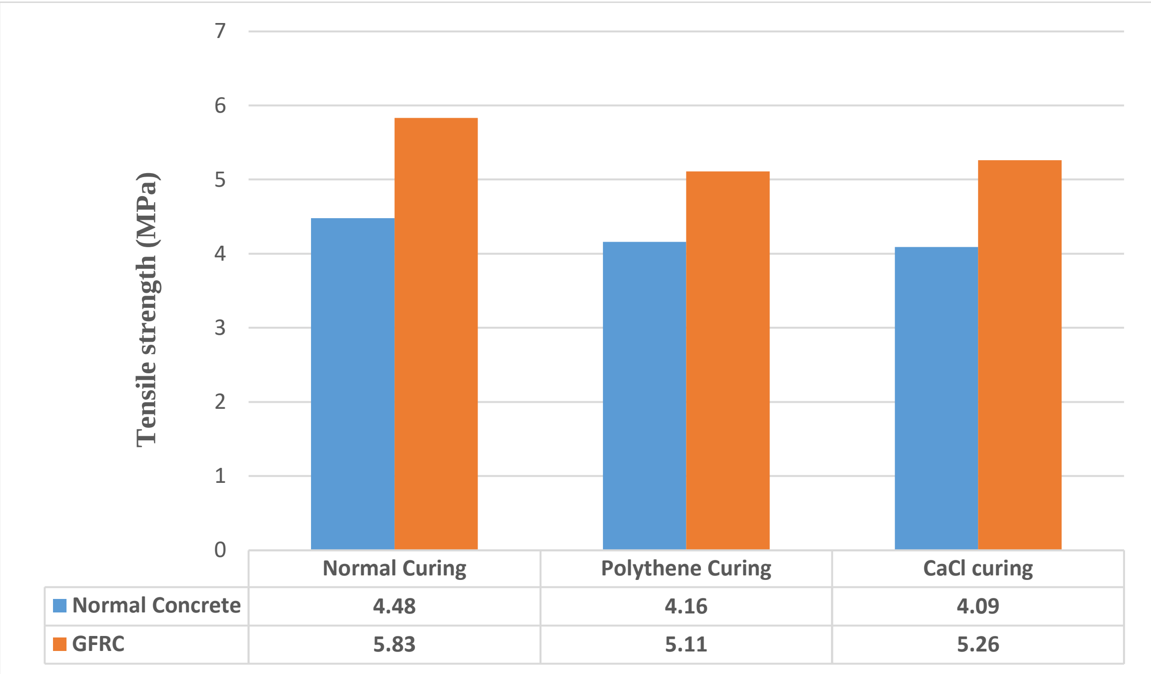

Figure 6: Tensile Strength after 90 days of exposure of NaCl (5%) solution

Strength loss due to Sulfate attack

In the case of normal curing when both normal concrete and GFRC were immersed in 5% of Sodium sulfate solution, normal concrete showed the maximum strength loss for the three chemical exposure periods of 30, 60 and 90 days. There was a drastic increase in strength loss as the chemical exposure period also increased. For a chemical exposure period of 30 days, normal concrete and GFRC showed 12.75% and 12.70% strength loss respectively under normal curing. The strength loss increased to 22.05% and 20.77% in case of 90 days of chemical exposure for normal curing. In the case of Calcium chloride integral curing, normal concrete suffered 15.83%, 20.89% and 24.13% strength loss under 30, 60 and 90 days of chemical exposure respectively. For Glass fiber concrete, the strength loss percentages were 13.51%, 15.9% and 20.66% for 30, 60 and 90 days of chemical exposure. Polythene curing resulted in a strength loss of 14.99%, 20.3% and 26.64% in the case of Normal concrete under chemical exposure periods of 30,60 and 90 days respectively. In the case of GFRC the strength loss percentages were 14.49%, 16.09% and 21.34% respectively. There was a tensile strength loss of 18.8%, 16.85% and 17.6% for normal concrete under normal curing, Polythene curing and calcium chloride integral curing respectively under a chemical exposure of 90 days. In the case of GFRC the tensile strength losses were observed as 17.82%, 16.78% and 17.29% for the above said respective conditions.

The above results indicates that the highest strength loss was in the case of calcium chloride integral curing. The presence of calcium chloride resulted in multiple effect. The higher strength loss for both normal and GFRC under calcium chloride integral curing was due to the combined effect of chlorite attack and sulfate attack. Sulfate attack resulted in gypsum and ettringite formation which resulted in expansion of concrete. It also lead to the decalcification of Calcium Silicate Hydrate (C-S-H). Sulfate ions react with hydrated calcium aluminate or the calcium hydroxide component of the cement paste and will result in the formation of Calcium sulpho-aluminate hydrate (Ettringite). The above reaction also can lead to the formation of calcium sulphate hydrate (Gypsum). Both ettringite and gypsum are expansive minerals and will lead to spalling of concrete.

C3A.CS.H18 + 2CH +2S +12H → C3A 3CS. H32 (Ettringite)

C3A.CS.H18 + 2CH + 3S + 11H → C3A 3CS. H32 (Ettringite)

$Na_2SO_4 + Ca(OH)_2 + 2 H_2O \rightarrow CaSO_4.2H_2O$(Gypsum) + 2 NaOH

Carbonates in the concrete will react with sulfate ions, C-S-H and calcium hydroxide are hence decomposed to form Thaumasite ($Ca.SiO_3.CaSO_4.15H_2O$) which also leads to strength reduction

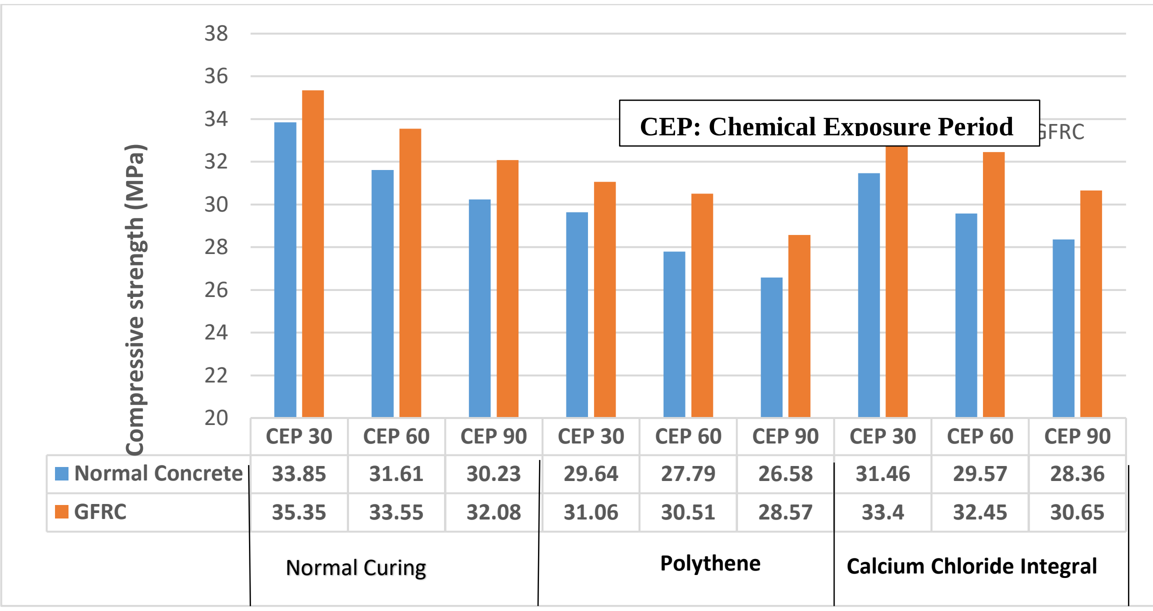

Figure 7: Comp. Strength after 30, 60 and 90 days of exposure of Na_2SO_4 (5%) solution

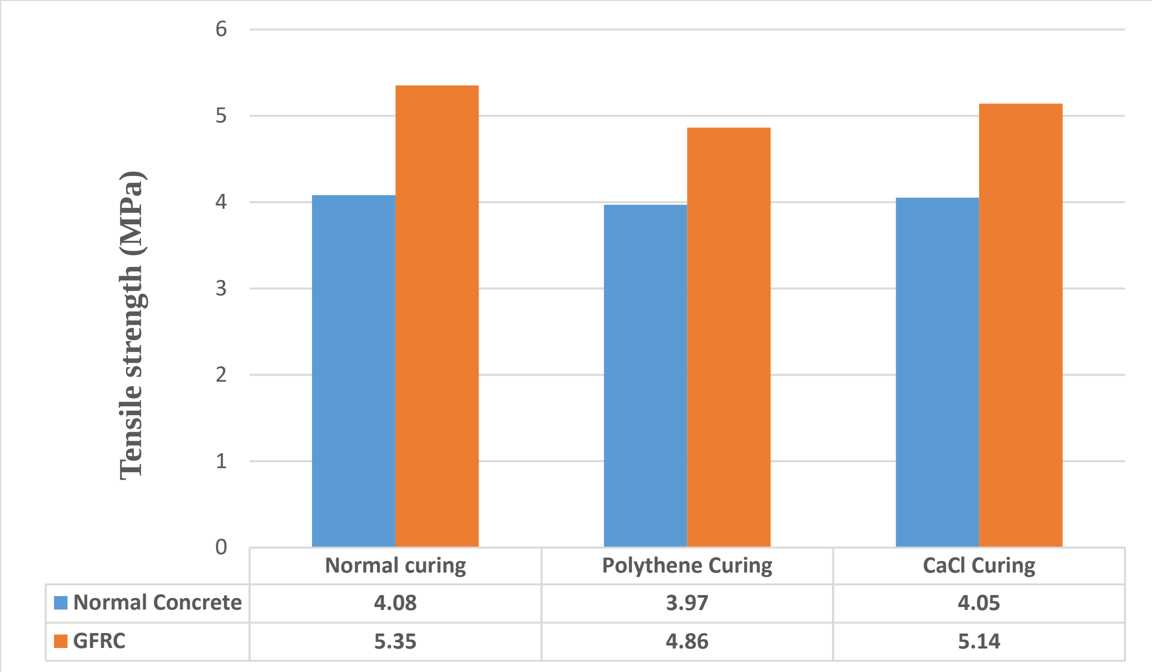

Figure 8: Tensile Strength after 90 days of exposure of Na_2SO_4 (5%) solution for three types of curing

Strength loss due to Acid attack

When both Normal concrete and GFRC are immersed in a solution of 5% sulphuric acid, there is a considerable decrease in its strength. Normal concrete showed more strength loss under the three curing conditions showed the maximum strength loss when compared with GFRC. The presence of fibres helped the GFRC to resist the acid attack to a small extend. Under normal curing, normal concrete showed 20.08%, 27.54%, and 32.13% compressive strength loss up on 30,60 and 90 days of chemical exposure duration. While GFRC showed 15.02%, 22.92% and 29.07% of strength loss under the similar conditions. In the case of Polythene curing, there was a strength loss of 34.07% and 30.01% for normal concrete and GFRC respectively under a chemical exposure period of 90 days. Calcium chloride integral curing suffered the highest compressive strength loss for both normal concrete and GFRC. There was a strength loss of 35.6% and 33.9% for Normal concrete and GFRC under a chemical exposure period of 90 days. There was a tensile strength loss of 25.81%, 26.61% and 27.95% for normal concrete under normal curing, Polythene curing and calcium chloride integral curing respectively under a chemical exposure of 90 days. In the case of GFRC the tensile strength losses were observed as 25.19%, 26.54% and 26.89% for the above said respective conditions.

In this case also, calcium chloride integral curing suffered the highest strength loss. Sulfuric acid attack resulted in the extensive formation of gypsum, which is the major reason for spalling. The percentages of strength loss increased with the increasing days of chemical exposure. Most of the concrete cubes suffered discoloration and the there was a considerable increase in the volume, this can be explained by the formation of Gypsum. Gypsum is expansive in nature. It results in spalling of concrete. The surface of the cubes were deteriorated because of it. The formation of calcium sulfate results in increases porosity and increased degradation. The presence of calcium sulfate also triggers sulfate attack, which again reduces concrete strength.

$$Ca(OH)2 + H2SO4 \rightarrow CaSO4 + 2\ H2O$$

$$3CaO.2SiO_2.\ 3H_2O + H_2SO_4 \rightarrow CaSO_4.\ 2H_2O + Si\ (OH)_2$$

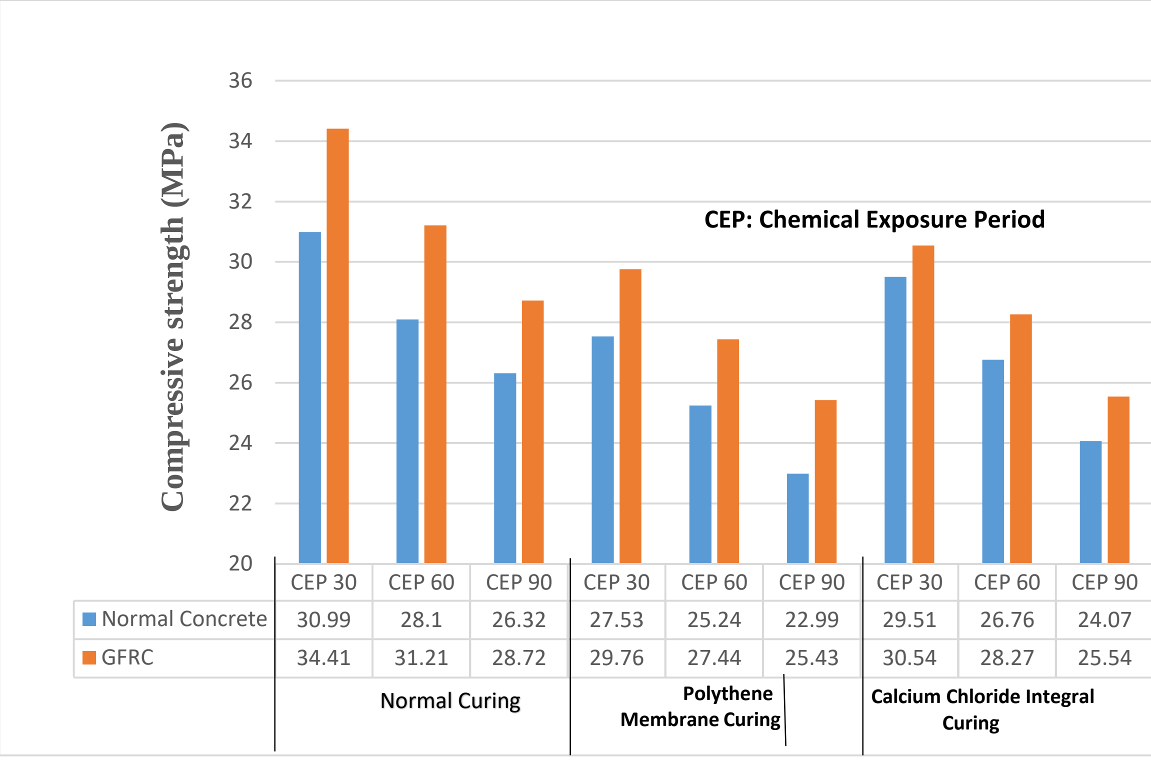

Figure 9: Comp. Strength after 30, 60 and 90 days of exposure of H_2SO_4 (5%) solution

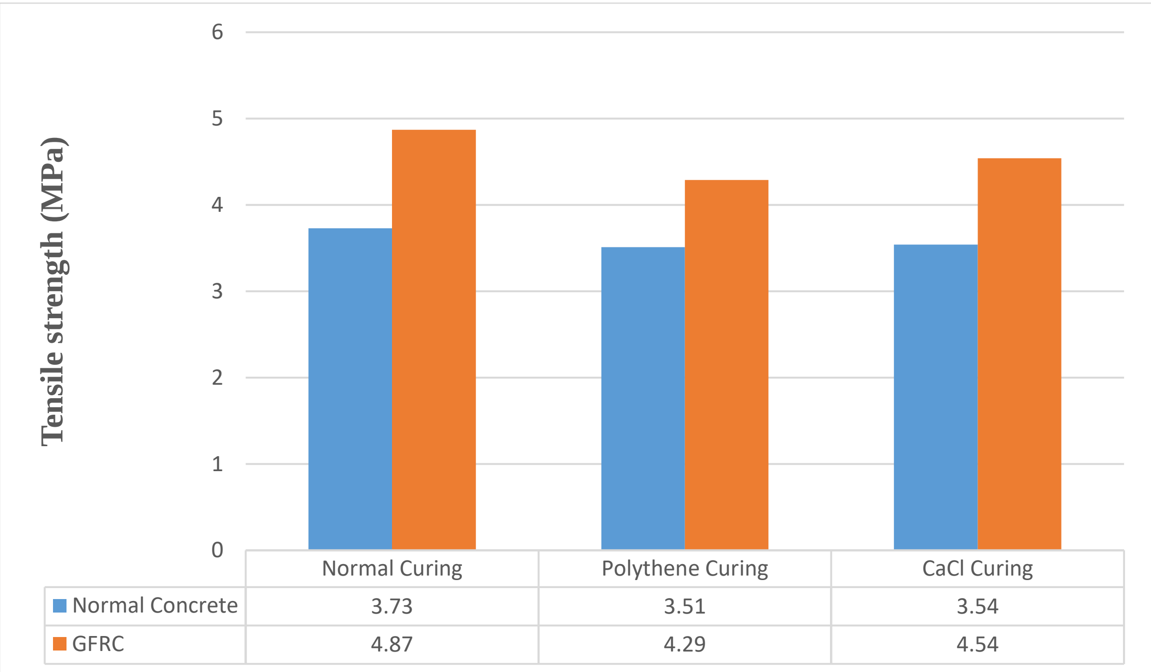

Figure 10: Tensile Strength after 90 days of exposure of H_2SO_4 (5%) solution for three types of curing

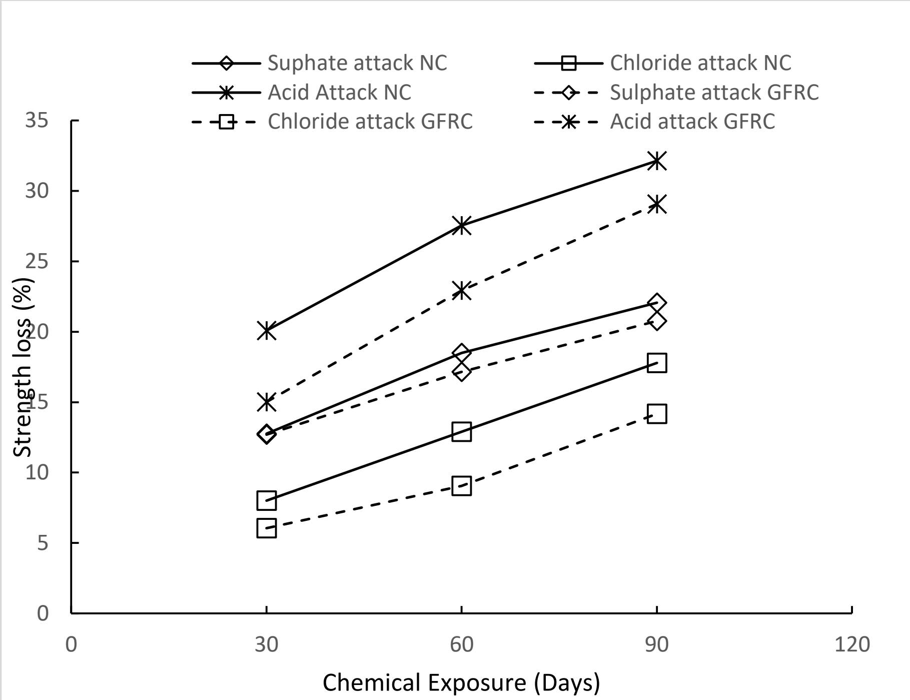

Figure 11: Strength loss for Normal concrete and GFRC under Normal curing

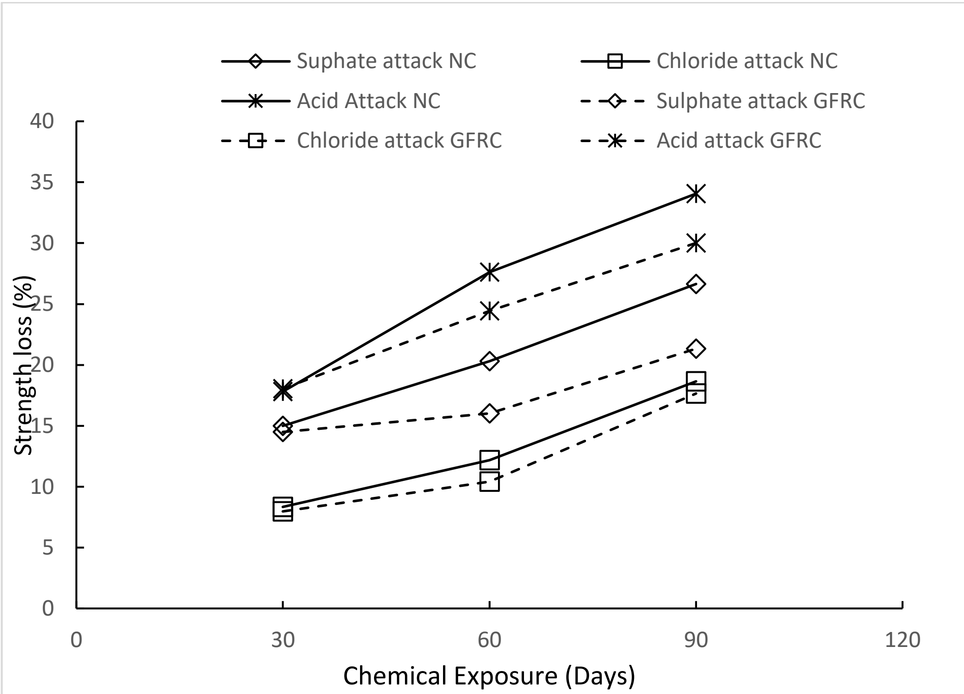

Figure 12: Strength loss for Normal concrete and GFRC under Polythene Membrane

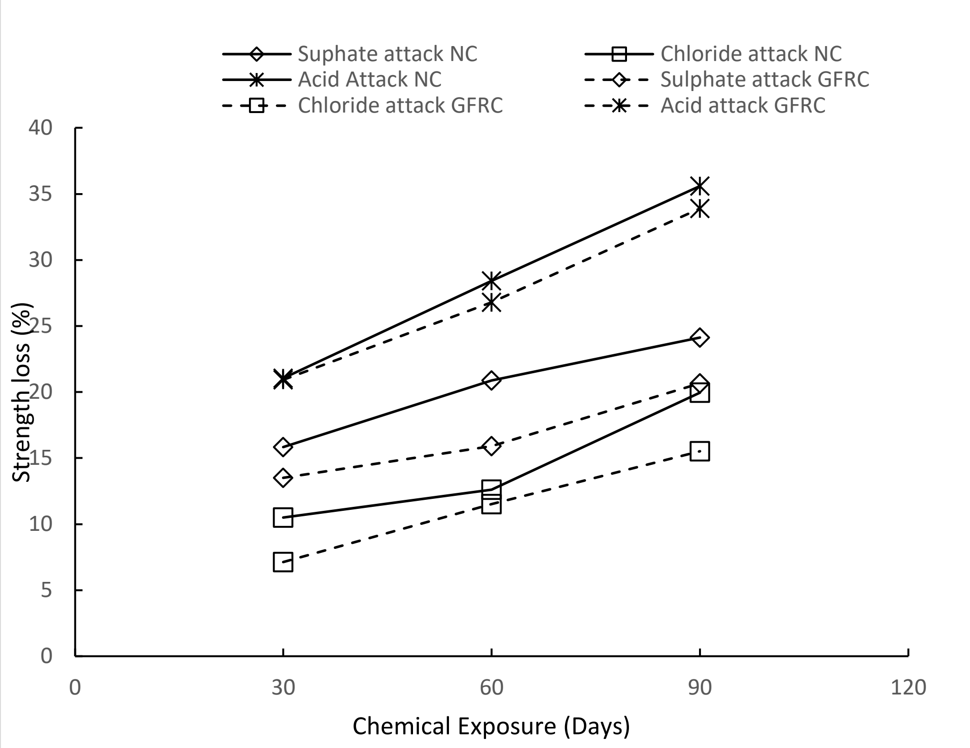

Figure 13: Strength loss for Normal concrete and GFRC under Calcium chloride Integral Curing

Weight loss Under Chemical attack

In the case of Chlorite attack, Normal concrete under calcium chloride integral curing suffered the maximum strength loss. For all the three curing conditions, weight loss increased as the chemical exposure period increased. For normal concrete under calcium chloride integral curing, there was a weight loss of 2.57% when subjected to a chemical exposure period of 90 days. But in the case of Glass fiber concrete, the respective weight loss percentage was 2.21%. In the case of Polythene membrane curing, normal concrete and glass fiber concrete suffered 2.32% and 1.71% weight loss respectively under a chemical exposure period of 90 days. Normal curing resulted in the least weight loss for both normal and GFRC under the three chemical exposure periods.

In the case of Sulfate attack, Glass fiber concrete under normal curing suffered the least weight loss (5.44%) when compared with normal concrete under the different types of curing. Maximum weight loss of 7.22% was observed in the case of normal concrete under calcium chloride integral curing. Normal concrete and Glass fiber concrete under polythene curing when subjected to a chemical exposure period of 90 days suffered weight loss of 7.15% and 5.78% respectively. The presence of glass fibers greatly reduced weight loss when compared with normal concrete.

Among the three chemical attacks, acid attack had the most severe impact on both strength and weight of the concrete. Normal concrete under calcium chloride integral curing suffered the maximum weight loss (12.56%) under the chemical exposure period of 90 days. The least weight loss under 90 days of chemical exposure was observed in the case of glass fiber concrete under normal curing. Normal concrete and GFRC under polythene curing suffered 12.7% and 10.78% weight loss when subjected to 90 days of acid exposure respectively. The weight loss percentage increased exponentially as the chemical exposure period increases.

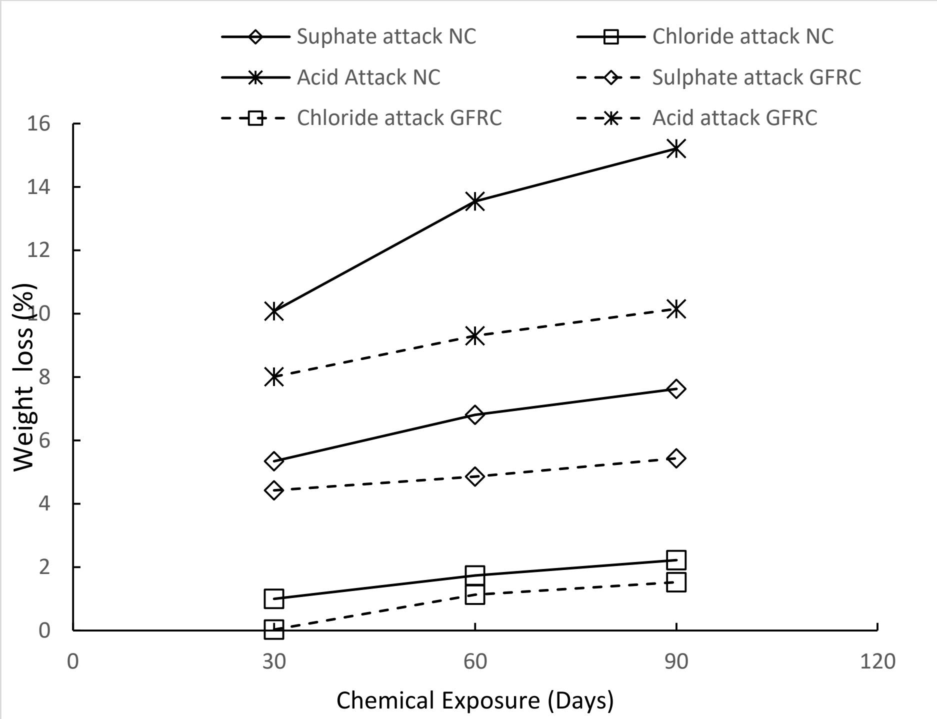

Figure 14: Weight loss for Normal concrete and GFRC under normal Curing

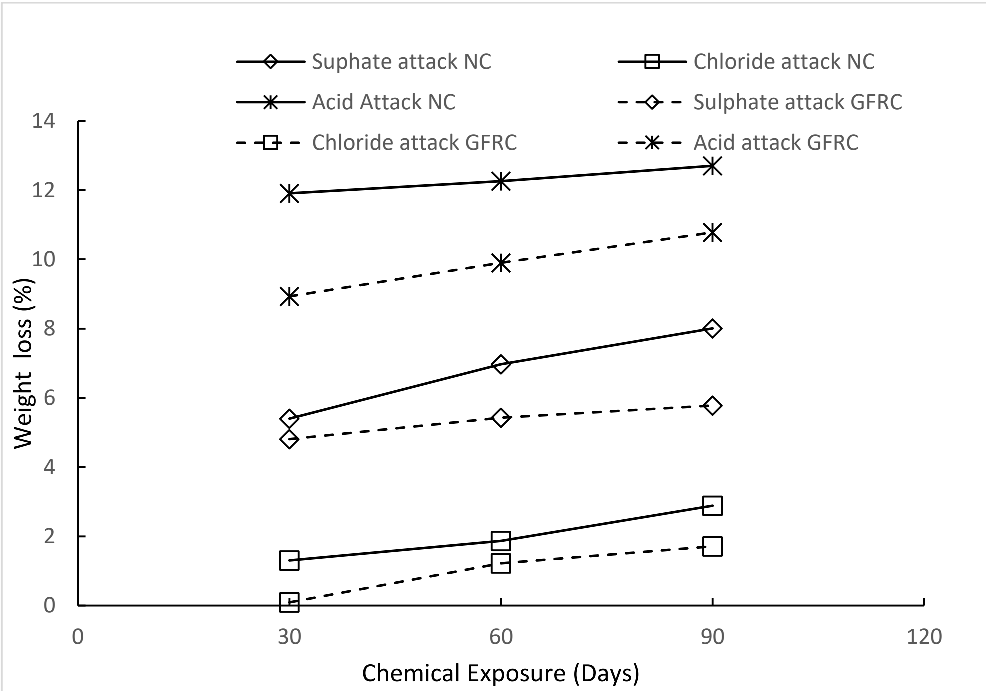

Figure 15: Weight loss for Normal concrete and GFRC under Polythene membrane Curing

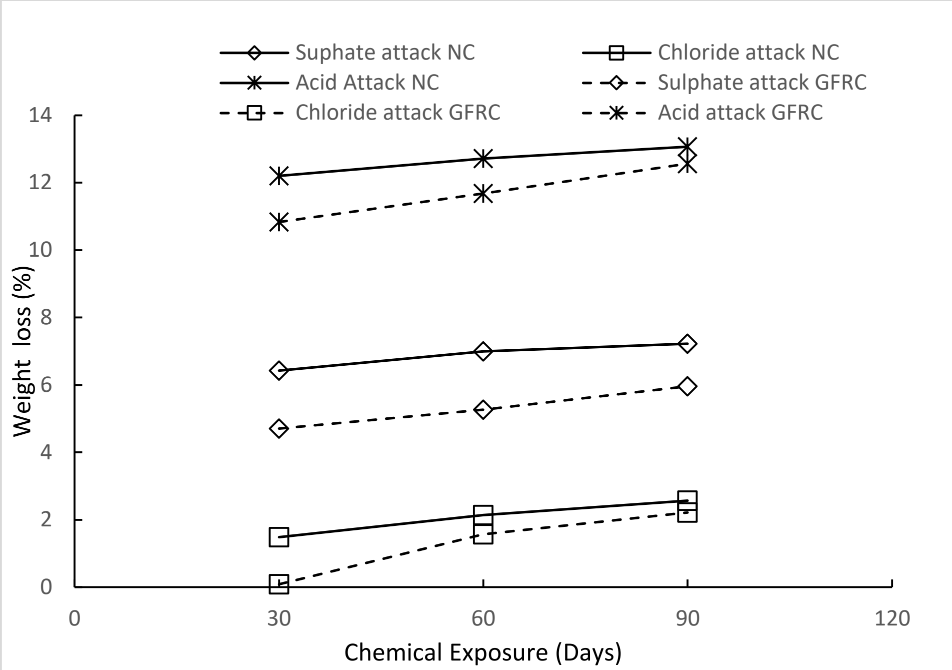

Figure 16: Strength loss for Normal concrete and GFRC under Calcium chloride Integral Curing

3.2 **Sorptivity characteristics**

Capillarity rise in normal concrete under calcium chloride integral curing is the maximum. The development of pores in the normal concrete lead to the higher capillary rise. Pores acted as a path for the water to rise from the bottom. Least capillary rise was observed in the case of glass fiber concrete under normal curing. The inclusion of glass fibers not only increased the strength but also hindered the path of water in the case of capillary rise. This resulted in less absorption of water and hence less sorptivity value.

Table 3. Weight characteristics and Sorptivity values of GFRC and Normal concrete.

Concrete Type	Type of Curing	Dry Weight In grams (W1)	Wet Weight In grams (W1)	Sorptivity value (10^{-5}mm/min$^{0.5}$)
Normal Concrete	Normal Curing	1048.9	1049.9	1.03
	Polythene Curing	1039.52	1040.9	1.05
	Calcium Chloride Integral Curing	1021.47	1023	1.48
Glass Fiber Concrete	Normal Curing	1058.1	1059	0.92
	Polythene Curing	1049.4	1050.5	1.14
	Calcium Chloride Integral Curing	1036.9	1038.1	1.27

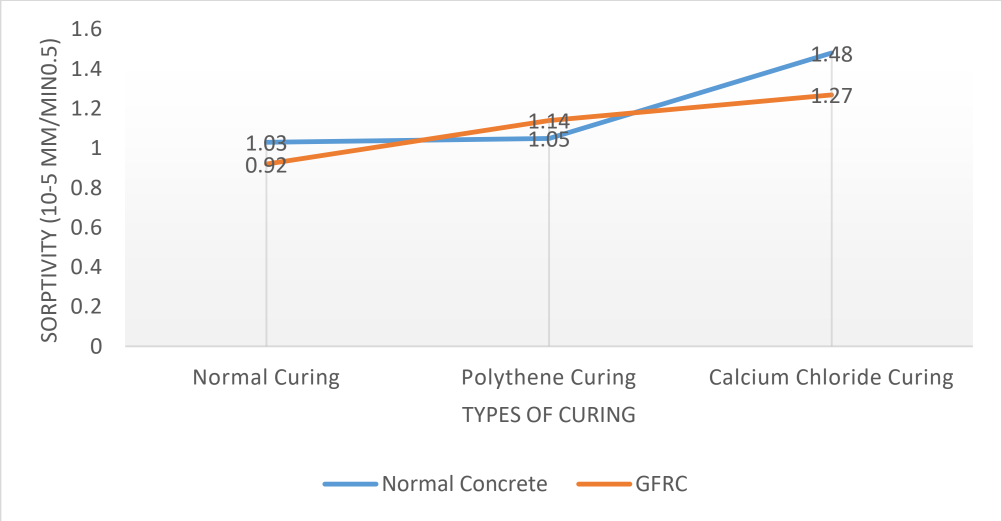

Figure 17: Sorptivity value of Normal concrete and GFRC

4. Conclusions

1. Increase in chemical exposure days resulted in increased strength loss and weight loss for both Normal concrete and GFRC.
2. In the case of salt attack and acid attack, normal concrete under calcium chloride integral curing resulted in the highest strength loss and weight loss due to decalcification and leaching.
3. In the case of sufate attack, normal concrete under polythene membrane curing resulted in the highest strength loss and weight loss due to the formation of Ettringite and Gypsum.
4. Normal concrete under calcium chloride integral curing suffered the highest capillary rise of water (Sorptivity).
5. The inclusion of glass fibers in the GFRC resulted in superior durability characteristics than that of Normal concrete under different chemical attacks.

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