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# Use of Geopolymer Composites for Controlling Structural Cracks

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**_Abstract_**

*A building's safety and stability can be compromised by ignoring the potential structural issues indicated by occurring cracks in buildings. Extensive damage may cause over the period from unidentified cracks.. Good quality concrete never cracks in normal service conditions unless high horizontal force is applied. Through the cracks, carbon dioxide is released into the concrete and speeds up carbonation throughout the cracks, thus reducing the structure usage. The materials which are involved in construction, diminish due to chemical reactions. The common kinds of chemical reactions in building materials are carbonation in cementitious materials, alkali-aggregate reaction, sulfate attack on cement products, and corrosion over reinforcement in concrete. Concrete may crack due to expansive reactions between aggregate, which accommodate alkaline derived and active silica from cement hydration. This paper describes Glass Fibre fiber-reinforced polymer as the best remedial material for structural cracks. Geopolymer may be used to repair structural defects by several procedures, including patching, spraying, and injecting. The repairs are often durable making them a dependable alternative for restoring structural integrity. This paper focuses on the chemical reaction's role in the formation of structural cracks and the use of geopolymer composites for remedial measures. This article is very beneficial to be aware of the identification of unaddressed cracks due to chemical processes and the economic measures to prevent structural integrity and stability.*

**Keywords:** Geopolymer, GFRP, Structural cracks; Reinforced Polymer; Composite Material.

## INTRODUCTION

Polymers can be of several types depending on the properties and technical parameters. Polymer plays a vital role as a remedial measure for structural cracks in construction elements. A building's overall structural integrity can be improved by recognizing and addressing identified issues, opportunity provided by cracks in buildings can be a reason for concern. Understanding the origin reason of these cracks is critical in identifying suitable obstructive measures and repair methods. There can be several reasons of cracks occurrence like earthquake damage, drying shrinkage, uneven settlements, alkali-aggregate reactions. Building structures are in moving condition whole time, but usually, these movements are so small-scale as to be unnoticeable. This motion can be caused by errors, changes in surface conditions, settlement in foundations, and so on. The crack appearance and other deformation caused by movements in buildings can be visually unnoticeable and uncomfortable for residents and can affect the safety, integrity, and stability of the structure if left untreated [1]. Corrosion in reinforcement will generate hydroxide and iron oxide on the steel bar surface, and volume increases as an outcome [2]. This expansion in magnitude creates giant radial rupture stresses throughout

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reinforcing bars and confined radial cracks occur due to this. These cleave cracks result in the development of longitudinal cracks similar to the bar. If reinforcement is not protected appropriately, reinforcement corrosion will occur [3]. Reinforcement steel can be safeguarded by giving sufficient impermeable concrete cover. This will avoid the access of moisture and other ambitious elements. Due to having a high pH value in nature in alkaline, corrosion in steel will not be created over concrete surroundings [4].

## CHEMICAL REACTION IN STRUCTURAL ELEMENTS

Chemical reactions result in a substantial increase in the volume of the material in construction elements that can produce cracking and rupture [5]. The generated surface cracks start the corrosion process fuelled by highly polluted air mixing with ambient humidity and condensation due to the temperature differential of overground and underground structures [6]. The reaction's components deteriorate as well.

- Sulfate attack is an illustration of a chemical reaction
- Carbonation of materials made of cement.
- Reaction between alkali and aggregate

### Sulfate Attack

Sulfate attack is a chemical malfunction procedure where sulfate atoms particles attack cement paste components [7]. The synthesis responsible for sulfate attacks is water soluble sulfate containing salts, such as calcium, magnesium, sodium, and potassium sulfate that chemically react with concrete components. Sulfate internally originates from concrete-making materials like hydraulic cement, admixtures, aggregates, and fly ash [8]. Sulfate external sources are more common like high-sulfate soils and ground waters [9]. The chemical reaction of sulfates with cement paste’s hydrated calcium aluminate and hydrated lime to form calcium sulpho-aluminate and calcium sulfate [10]. The tensile stresses formed due to expansion lead to the development of the crack in concrete [11]. The reaction of sodium sulfate ($Na_2SO_4$) with calcium hydroxide develops gypsum, which decreases the cement paste stiffness and strength [12]. Figure 1. shows the basics of the sulfate attack mechanism.

### Carbonation

The development of calcium carbonate ($CaCO_3$) by a chemical reaction, is known as carbonation in concrete. It is the effect of carbon dioxide from the environment which reacts with alkaline substances in concrete converting the calcium hydroxide to calcium carbonate in the presence of moisture [13]. The calcium carbonate develops due to three substances: calcium phases (Ca), carbon dioxide ($CO_2$), and water ($H_2O$). Concrete contains calcium phases, carbon dioxide, and water, which react in pores to form carbonic acid ($H_2CO_3$). Calcium Oxide (CaO) is released from hydrated CSH in cement paste, causing a decrease in pH, with the normal concrete pH being above 13 and fully carbonated concrete below 9 [14]. The carbonation process initiates the corrosion on the reinforcement [15]. There are two main parameters on which the carbonation speed process through the porosity of concrete and the moisture content available in the concrete [16]. The carbonation process is slow in good-quality concrete as compared to poor quality [17]. As the porosity is lesser, the penetration of $CO_2$ will also be lesser [18]. The process of carbonation (Figure 2) requires changes due to reactions in the moisture levels (dry to damp to dry).

### Reaction Between Alkali and Aggregate

Specific types of aggregate and sand such as volcanic, opal, and chart with a high volume of silica content are reactive with sodium hydroxide, calcium, and potassium available in Portland cement concrete [19]. This occurrence of a chemical reaction is known as an alkali-aggregate reaction. The alkali-aggregate reaction can cause spalling and loss of concrete strength [20]. The alkali-silica reaction (ASR) is a chemical reaction can be represented schematically as follows:

$$Ca(OH)_2 + H_4SiO_4 \rightarrow Ca^{2+} + H_2SiO_4^{2-} + 2H_2O \rightarrow CaH_2SiO_4 \cdot 2H_2O$$

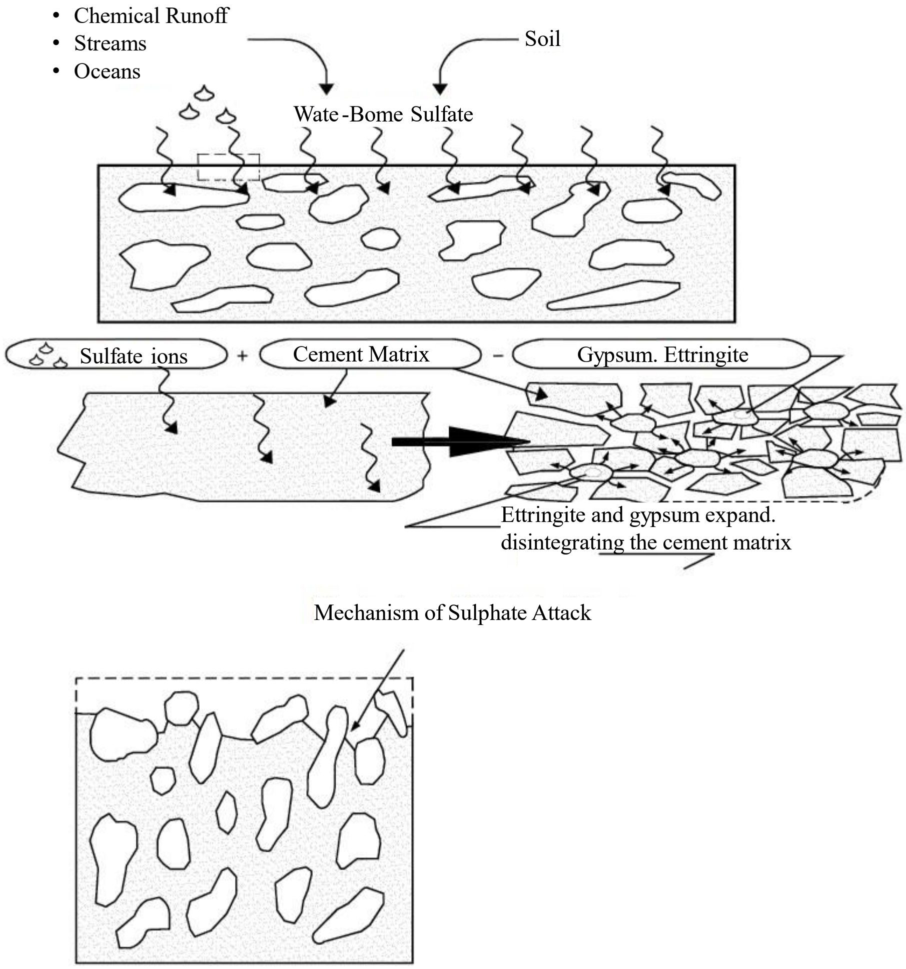



**Figure 1.** Sulfate Attack Mechanism.

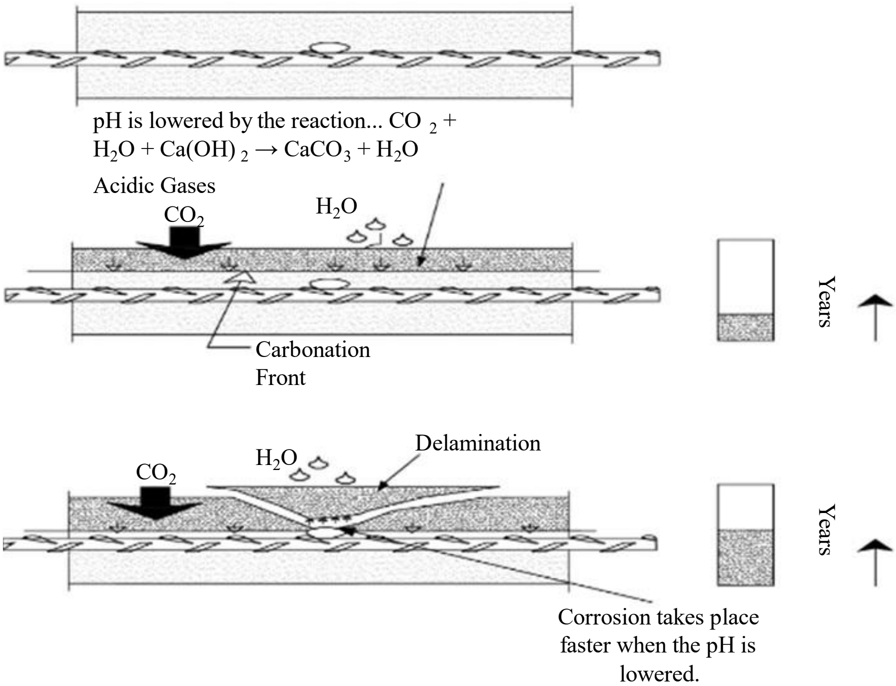



**Figure 2.** Carbonation Process.

The deterioration of concrete due to the ASR mechanism (Figure 3) can be described in steps as follows:

- The siliceous aggregate is transformed into an adhesive alkali silicate gel due to the attack of an alkaline solution.
- The chemical reaction between calcium ions and alkali silicate gel in cement pore water leads to the dissolution of $Ca^{++}$ ions and the formation of hard C-S-H.
- The solution penetrated alters the balance of siliceous minerals, transforming them into a substantial alkali silicate gel.
- The aggregate and their cement paste are cracked due to collective pressure exceeding the aggregate tolerance.

The ASReffect (Figure 4) can be detected by physical appearances like concrete expansion and cracks affecting its structural elasticity, durability and strength, spalling of concrete, visible map cracking, and discharge of alkali-silica gel.

The alkali-carbonate reaction can degrade the concrete with dolomite aggregate. This mechanism can be schematically proposed as follows:

$$31CaMg(CO_3)_2 + 2NaOH \longrightarrow CaCO_3 + Na_2CO_3 + Mg(OH)_2$$

ACR is relatively rare because dolomite aggregates are usually unsuitable for use in concrete.

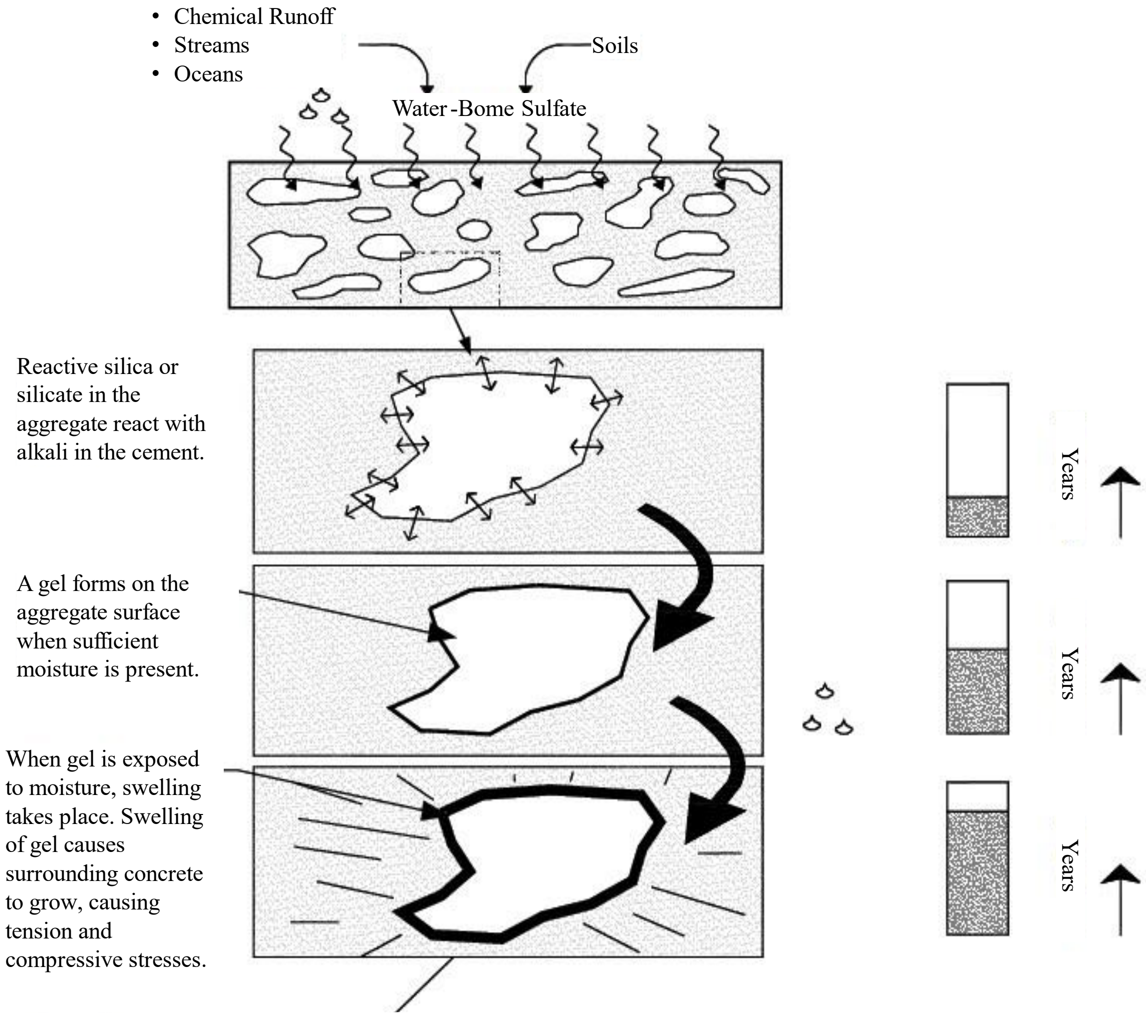



**Figure 3.** Alkali-Silica Reaction.

**Figure 4.** Typical Effect of Alkali-Aggregate Reaction.

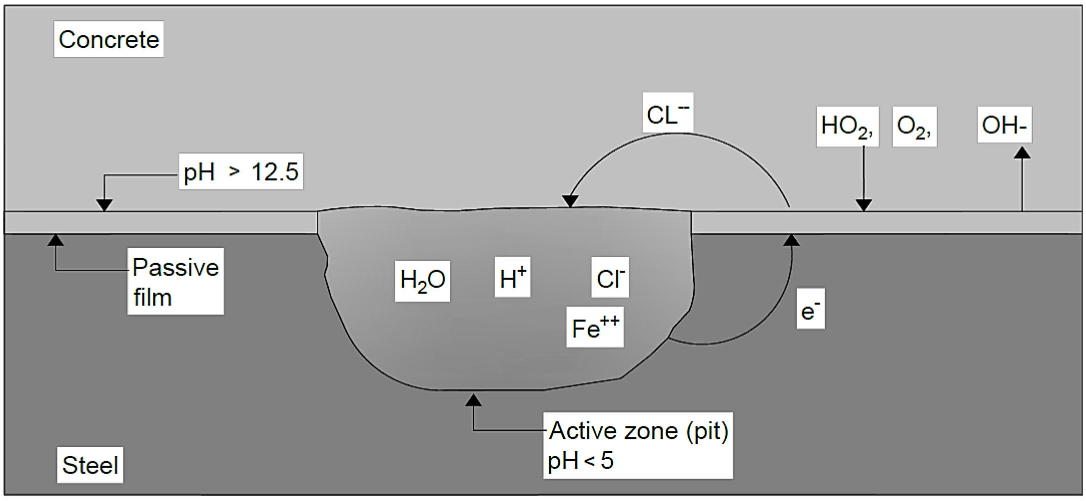



**Figure 5.** Chloride Attack Mechanism.

### Chloride Attack

Chloride attack is the most impending opponent when considering the durability of concrete. Almost in 40% of the failure of concrete structures, a Chloride attack is responsible. Structural strength can drastically reduce to corrode the steel by chloride attack [21]. Figure 5. shows the basics of the chloride attack mechanism. Corrosion occurs when chloride ions react with steel and the surrounding passive material, resulting in the formation of hydrochloric acid [22]. Hydrochloric acid degrades steel reinforcement, causing concrete cracking, spelling, and eventual failure [23].

#### *Damages*

Steel corrosion causes concrete cover spalling, causing porous oxide that takes up to 10 times the steel volume, leading to concrete break-up [24]. Horizontal cracks in material interface cause concrete cover loss due to oxide formation, while vertical cracks occur when steel's tensile strength exceeds. If rust stains are identified around spalls and cracks, these are symptoms of a chloride attack (Figure 6).

## STUDY OF DIFFERENT TYPES OF CRACK PATTERNS

### Diagonal Cracks

Due to inadequate cross section and lesser reinforcement steel, diagonal cracks in the reinforced concrete column occur as shown in the figures. In Figures 7, 8, and 9, diagonal horizontal and bond cracks are shown (Tables 1–3)

**Figure 6.** Chloride Attack Effects over Concrete and Reinforcement Steel.

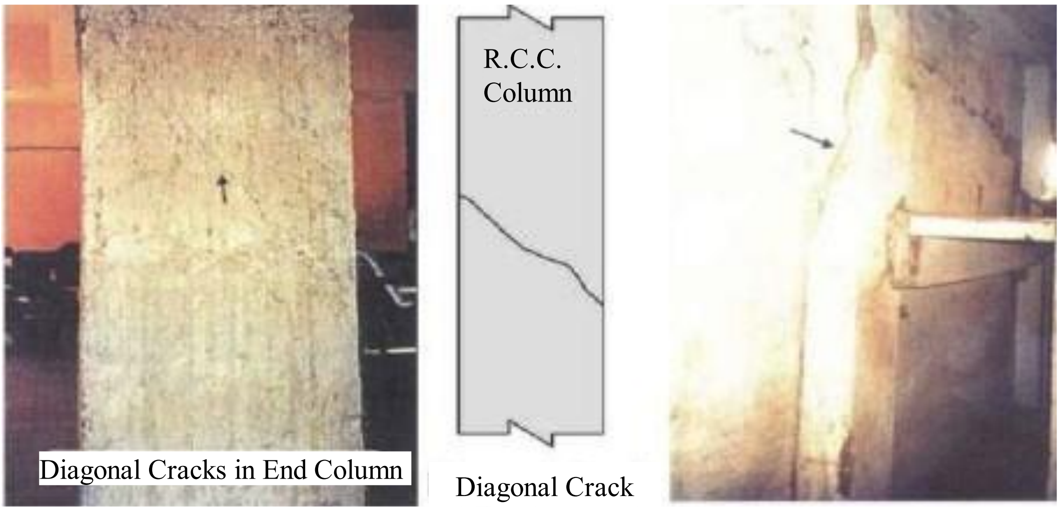



**Figure 7.** Diagonal Cracks Due to Inadequate Load Carrying Capacity.

**Table 1.** Diagonal Crack Details.

| Member | Crack Type | Important Characteristic | Possible Reasons |
|---|---|---|---|
| Reinforced Concrete | Reinforced Concrete Diagonal Cracks | Across the section, Run diagonally | Insufficient load carrying capacity of the column. |
| | | Can occur anywhere in the height | Cross section or main reinforcement is insufficient |
| | | Uniform thickness | |

### Types and reasons of Horizontal Cracks in concrete

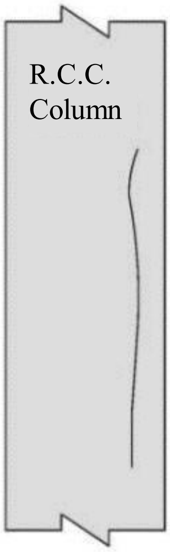

**Figure 8.** Horizontal Cracks Due to Moment Resistance.

**Table 2.** Horizontal Crack Details.

| Member | Crack Type | Important Characteristic | Possible Reasons |
|---|---|---|---|
| Reinforced Concrete | Horizontal Cracks | Develop near Beam-Column junction | Insufficient moment resistance capacity of the column. |
| | | | Insufficientvolume of reinforcement or placement of reinforcement not satisfactory |

### Types and reasons of Bond Cracks in concrete




Bond Crack

**Figure 9.** Bond Cracks Due to Moment Resistance.

**Table 3.** Bond Crack Details.

| Member | Crack Type | Important Characteristic | Possible Reasons |
|---|---|---|---|
| Reinforced Concrete | Corrosion Cracks | Runs parallel to the line of reinforcement | Between reinforcing bars and concrete, the Bond not satisfactory |
| | | Uniform width in general | This may be due to the corrosion of bars |

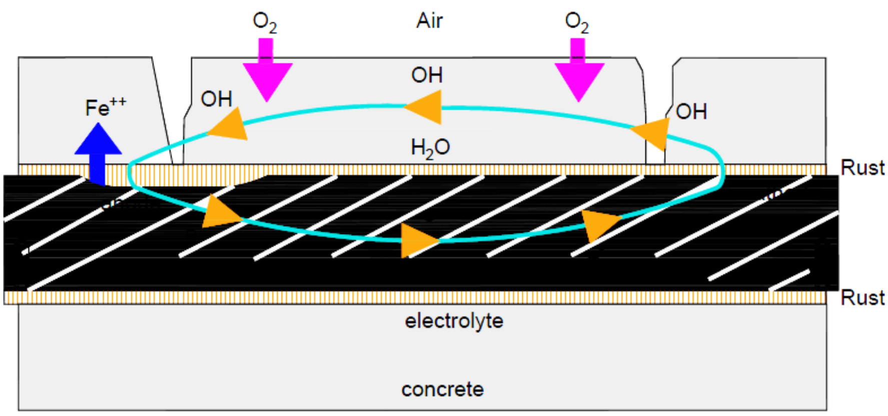



**Figure 10.** Corrosion Chemical Process in Structure.

### Brief on Corrosion in Structure

The steel reinforcement rusting process (Figure 10) is an electromechanical reaction [25]. During the carbonation process, the passive layer can worsen over the period due to atmospheric carbon dioxide ($CO_2$) [26].

Aggressive chemicals like chloride, also rapidly break down the passive layer. These chemicals are present in maritime environments. After compromising the passive layer, steel reinforcement rusts when oxygen and moisture are available at the steel's surface. Ensuing to corrosion, cracks are visible on the outer surface of concrete. These cracks will further improve and form into spalls to the point. Therefore, the presence of water is a must from penetrating the reinforced concrete to divert away from attacking the reinforcement steel within [27]. We can intercept the chemical reaction and destruction incurred due to corrosion by eliminating any of the three main components i.e. Oxygen, Steel, and water. This is the main reason that dry concrete has no corrosion and also the concrete which fully submerged in water has limited corrosion. The carbonation process reaches the cover's depth. The ultimate result is cracking, spalling, and corrosion (Figure 11).

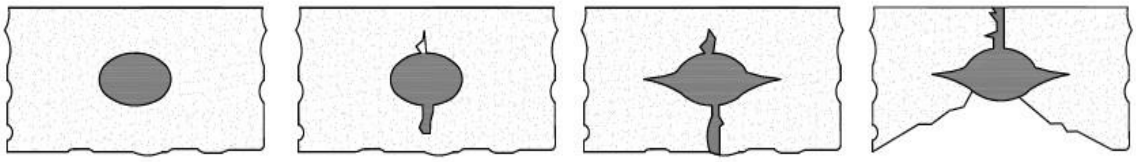



**Figure 11.** Corrosion Chemical Reaction (Before and After Stages).

## REMEDIAL MEASURES

Glass fiber-reinforced polymer is a composite substance which interlaced polyester material and fiber E-glass. GFRP has tensile and compressive strengths ranging from 44-2358 MPa, and can be hardened using thermosetting polymers like epoxy, thermoplastic, or resin, forming seamless shell structures. Glass fiber is pasted onto large areas using concrete or wireframe structures, repeated until desired thickness is achieved, then sanded down, and finished with wax coating or paint. GFRP is very useful to apply where corrosion reduces the actual design strength of concrete. GFRP can also be used to retrieve the damaged concrete structures. Glass Fibre wrapping is the latest technology for strengthening/enhancement of masonry and reinforced concrete structural members. It is used for shear, flexural, or confinement strengthening of structural members.

### GFRP Advantages

1. GFRP acts as Multifunctional elements which can be used in shear and in bending.
2. The weight of GFRP is low.
3. GFRP can be available in any length as per the requirement
4. It is flexible and can fit all around any desired structural element
5. It is excellent in weathering and chemical resistance
6. Overall thickness is low
7. Application is economical to use
8. Solvent-free impregnating resin is easy to use

### Procedure for Glass Fiber Reinforced Polymer (GFRP)

The column's surface should be roughened, cleaned with an air blower, then grinded before being cleaned with a high-pressure air jet. The technique called wet lay-up is to be used to wrap the FRP layers. In this technique, an iso-phthalic polyester resin is applied to the concrete column surface. Next, to cover the resin, the dry fibrous reinforcement material is wrapped all around. Remove the entrapped air bubbles by using a roller and press the resin to penetrate properly into the fabric. The roller is to be continuously used until the resin reflects on the fabric surface, a sign of fully wetting. Another layer of resin is applied on the top of the fabric. This process accomplishes one FRP repair layer. The process is to be repeated to apply subsequent layers. The wrapped sample was then left at room temperature to permit the curing of the bonded laminates. All the procedures are represented in Figures 12, 13, 14, and 15.

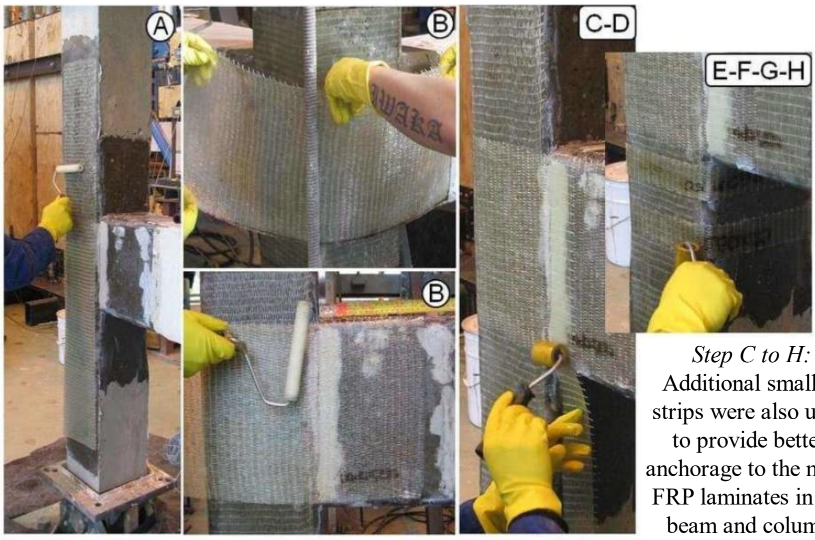
 

**Figure 12.** Application of Primer Coat or Coupling Agent.

**Figure 13.** Application and Fixing of GFRP.

**Figure 14.** Removal of Entrapped Air.




*Step A:*
Vertical FRP layer application on column

*Step B:*
Application of U-shape horizontal laminate wrapped around the exterior column at the joint level

*Step C to H:*
Additional smaller strips were also used to provide better anchorage to the main FRP laminates in the beam and column

**Figure 15.** GFRP Process.

**Method Statement For Glass Fiber Reinforced Polymer**

1. *Surface preparation 1 (All surfaces):* Preparation of column/beam/Slab surface soffits by diamond grinding/drilling to remove existing plaster layer, roundoff the sharp corner edges of columns to achieve foldless joints at corners, scrapping off old paint and sand blasting the surface to expose virgin concrete surface include air blowing all dust and disposal of all waste material.
2. *Surface preparation 2–Where concrete has spalled to expose rebar:* Cleaning reinforcement to original black steel color by complete rust removal using two or more coats of Sika-Rustoff-100 or equivalent followed with the application of two or more coats of Sika rustop-100 or equivalent as per manufacturer recommendations.
3. *Epoxy injection grouting*: Fixing MS-NRV nozzles by drilling holes 12-15 mm holes @ 250 c/c, securing the nozzles with Sikadur-31 Epoxy Mortar or Sikadur – 52 (IN) SLV+ Quartz Sand (1:5) Mortar or equivalent, injecting Sikadur-52 (IN) SLV where crack width is less than 6 mm or Sikadur-53 (FLV) where crack width is more than 6 mm till refusal sequentially as per manufacture specifications.
4. *Rebuild spalled concrete to original shape:* Applying Sika Mono Top 122 F/Thixotropic repair Mortar Master Emco-S 348 or equivalent to rebuild the broken /spalled concrete surface and edges to the original shape as per manufacturer recommendations. The thickness may vary from 10 mm to 60 mm.
5. *GFRP wrapping*: Fixing GFRP wraps around the selected areas as per the following steps complete in all respects:
   - Application of Master Brace P3500 Epoxy primer or equivalent on the clean prepared surface to receive Glass fiber wrapping as per application guide to the manufacturer.
   - Installation of Tyfo SHE Shear Anchors or equivalent including drilling, cleaning, and filling the hole with Tyfo epoxy or equivalent.
   - Building up average laminate thickness of 1.3 mm with unidirectional Glass Fiber sheets – Master Brace Fibre-900 GSM or equivalent with Saturation resin Master Brace-4500 or equivalent in 3 to 4 layers as per application guide of the manufacturer (Figures 16–19).
6. *Sprinkling of sand:* Sprinkling of Fine Quartz sand on the column surface after rectifying air voids, if any to make the surface rough to take any further finishes.
7. *Protective cement plaster:* Applying 12-15 mm thick Cement Mortar (1:4) plaster on GFRP finished surface including preparing the surface, curing, etc. all complete.

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However, natural fiber-reinforced polymer composites are becoming increasingly popular in technological applications. The investigation of novel plants for their fibers can enhance/speed up the replacement of synthetic fibers by natural fibers [28–32].

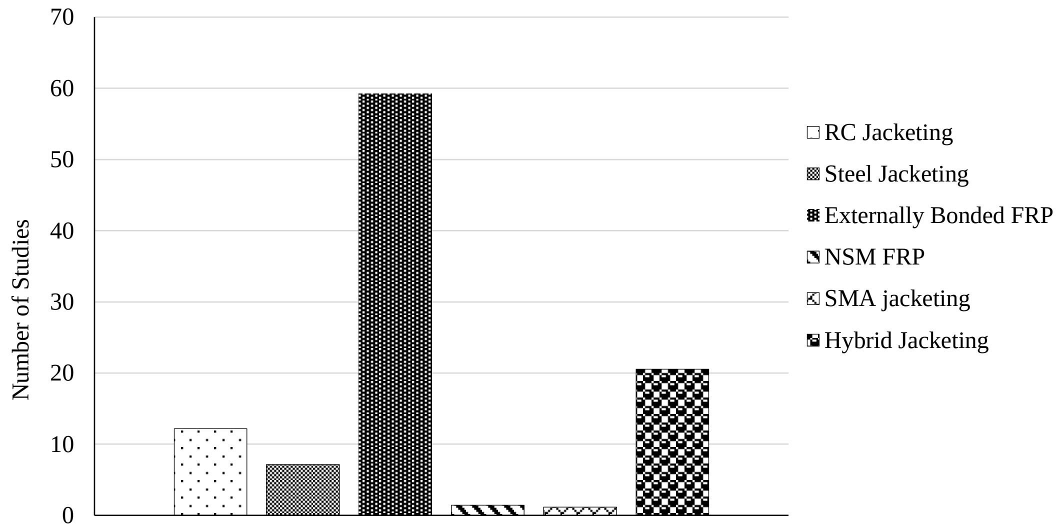
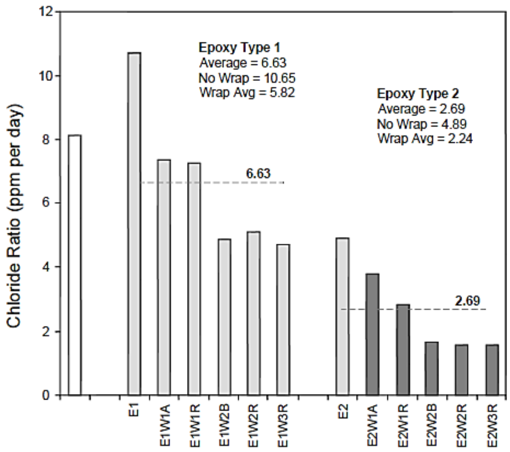



**Figure 16.** An Overview of the Experimental Studies on the Strengthening and Repair of Reinforced Concrete Columns.




| Style | Number of fiber - reinforced polymer wraps | Thermoset resin | Wrap fiber orientation | Number of samples | Average coating thickness (mm) |
|---|---|---|---|---|---|
| C | 0 | None | None | 03 | — |
| E1 | 0 | Epoxy 1 | None | 03 | — |
| E1W1A | 1 | Epoxy 1 | Axial -90° | 03 | 1.55 |
| E1W1R | 1 | Epoxy 1 | Radial -0° | 04 | 1.09 |
| E1W2R | 2 | Epoxy 1 | Radial -0° | 03 | 2.31 |
| E1W2B | 2 | Epoxy 1 | Bias-± 45° | 04 | 2.23 |
| E1W3R | 3 | Epoxy 1 | Radial -0° | 04 | 3.37 |
| E2 | 0 | Epoxy 2 | None | 03 | — |
| E2W1A | 1 | Epoxy 2 | Axial -90° | 03 | 1.88 |
| E2W1R | 1 | Epoxy 2 | Radial -0° | 03 | 1.78 |
| E2W2R | 2 | Epoxy 2 | Radial -0° | 03 | 2.57 |
| E2W2B | 2 | Epoxy 2 | Bias-± 45° | 03 | 3.30 |
| E2W3R | 2 | Epoxy 2 | Radial -0° | 03 | 4.09 |

**Figure 17.** Reduction of Chloride Content in Specimen Wrapped With Fiberglass Wrap.

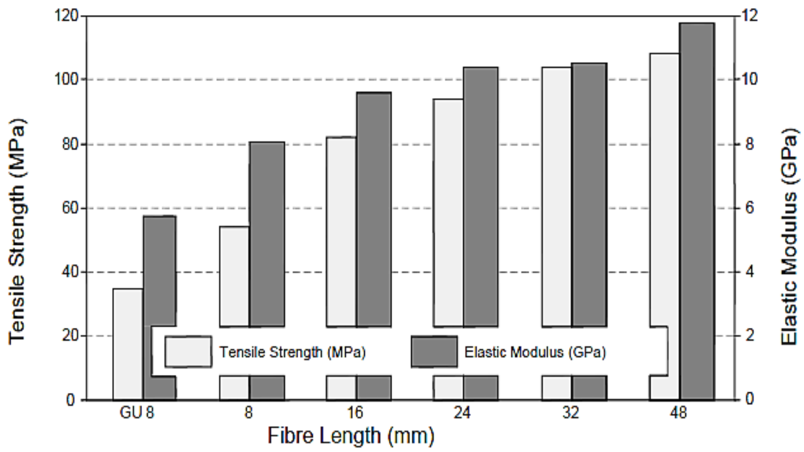



**Figure 18.** GFRP Properties.

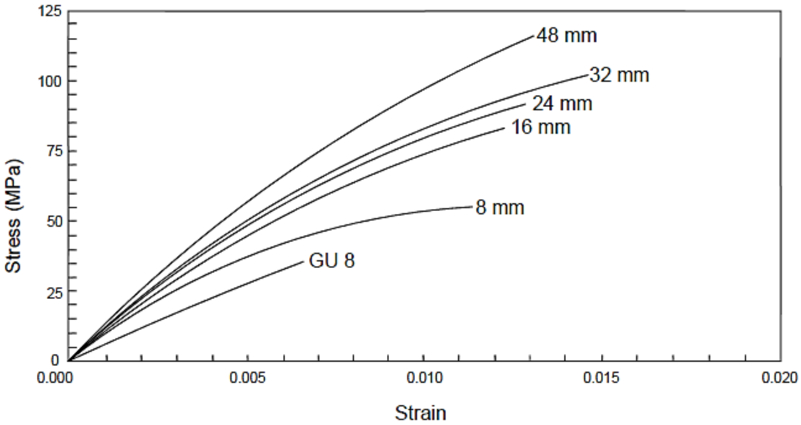



**Figure 19.** GFRP Stress-Strain Response.

## CONCLUSION

This study explained the perception of cracks types, reasons for the formation of cracks, and measures of cracks. Various types of cracks and reactions of chemicals are discussed in this study. It was observed that not all types of crack need the same level of treatment or consideration for measures. If proper consideration is given to construction techniques and materials that are to be used, the possible causes of cracks can be controlled. In the case of existing cracks, after a detailed study and analysis of crack parameters, the most convenient and suitable method of rehabilitation should be embraced for effective and efficient treatment of cracks. The process of applying the described solution as a measure is explained in detail with a graphical representation. Suitable techniques for the rehabilitation of cracks are also discussed in this study. Moreover, the use of geopolymers for corrective treatments offers a convincing approach for successfully addressing structural fractures/cracks. This method promotes sustainable construction practices as well as assures infrastructure safety. Extensive studies in this sector are required to fully realize the potential of geopolymers in structural repair and construction.

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