The Behavior of Polymer RC Columns Exposed to aggressive Soils

L. Sh Rasheed¹, Sh A Salih² and Z F Hanash³

¹ Civil Engineering Department, University of Kerbala, College of Engineering, Kerbala, Iraq. (laith.alqarawee@uokerbala.edu.iq)
² Building and Construction Department, University of Technology, College of Engineering, Baghdad, Iraq. (professorshakir@yahoo.com)
³ Civil Engineering Department, University of Kerbala, College of Engineering, Kerbala, Iraq. (zahraa7121992@yahoo.com)

Abstract. One of the most important properties about the durability of concrete is its resistance to sulfate attack. In this search, the effect of sulfate salts on reinforced polymer concrete columns was studied, the columns buried in two types of soil, sand and clay, in depth of 3 m, in one of the agricultural areas in the holy city of Karbala. The sandy soil comprised 10.609% of SO₃, the clay soil 2.61%SO₃. A compressive test for reinforced concrete columns, compressive test for concrete cubes and a tensile splitting test for concrete cylinders were applied, absorption, voids ratio and density also measured. A ratio of polymer / cement = 7.5% was found to reduce the compressive strength of polymer reinforced concrete columns buried in clay soil at ages 60, 150 and 240 days by 23.97, 20.28 and 24.96%. When buried in sandy soil, the decrease in strength was 31.12, 20.03 and 37.52 % respectively, in comparison to the reference column. From this it can be concluded that the use of a polymer (SBR) has negatively affected the strength of reinforced concrete columns after 150 days so is not recommended for use in concrete facilities which are subject to attack by sulfate salts.

Keywords. axial compression, sulfate attack, chloride attack, polymer concrete.

1. Introduction

In the groundwater and soil in southern parts of Iraq had sulfate ions which meaning that concrete structures in these regions are exposed to sulfate attack. This causes two types of harm; strength loss of the concrete due to the degeneration of calcium-silicate-hydrate (C-S-H), and expansion of volumetric due to the gypsum formation or ettringite that leads to cracking. Protection against attack of sulfate involves reducing the concrete permeability, as low permeability can extend the service live of a structure exposed to detrimental surroundings (Obla et al., 2006)(Laith Rasheed, 2018).

The present study aims to produce a polymer reinforced concrete that can withstand sulfate attack. This will involve evaluating the sulfate salts’ effect in groundwater and soil on the durability and strength properties of purely compression polymer concrete columns.

Seven reinforced concrete columns were tested for this investigation, 42 cubes used to measure the compressive strength, absorption, density and to measure voids. While 21 specimens of cylinder shape were used to estimate the splitting tensile strength. The samples were buried in sand and clay soils for up to 240 days, in an aggressive environment containing Cl⁻ + SO₄²⁻ at concentrations identical to those present in the soil and groundwater found in the south of Iraq region.
2. Experimental Work

2.1 Experimental Program

There were two series of specimens, first one buried in clay soil, the other in sandy soil. The primary details can be seen in Table 1. Each group consists of 3 columns, all longitudinally reinforced in the same way: 4 Ø 8mm with 7 Ø 6mm/m of stirrups, as shown in figure 1. All the columns were square and symmetrical in size at 150x150 mm and 1080 mm in height. All of them were poured in a perpendicular orientation and solidified in potable water for 28 days, then the specimens were buried and solidified in the soil with different sulfate and chloride concentrations for a period of 60, 150 and 240 days. The two sets of columns were examined under uniaxial constant force at the same time periods; 60, 150 and 240 days. Tests began with a 7 kN/m² load to set and check the dial gauge. At zero loading, an initial reading of the dial gauges is obtained, loading then applied in phases. At each additional load, notes and sketches were made of the development of cracks on the concrete specimens. The first seen cracking load with dial gauge readings were also documented (Laith Rasheed, 2018).

![Figure 1. R.C. tested columns details](image)

**Table 1. The mix design details**

| Mix Designation | Cement (kg/m³) | Sand (kg/m³) | Gravel (kg/m³) | SBR % | W/C  |
|-----------------|----------------|--------------|---------------|-------|------|
| Polymer         | 336            | 760          | 1044          | 7.5   | 0.475|
Portland Cement (ASTM-Type V) ([ASTM/C150, 2005] of Sulfate Resist commercially recognized as AL-GESR, was used through this work. This cement complies with Specification No.5/1984 (Iraqi/Specification). Fine aggregate from Al-Ukadir area was also used, this falling within Specification of IQS No.45/1984 (Iraqi/Specification). Coarse aggregate with maximum size 20 mm from Al-Nabi region, were used in all mixes, conforming to IQS No.45/1984 (Iraqi/Specification). A clean drinking water from the water-supply network system was used in the mix design. There were no suspended solids and organic matter in the mixtures that could affect the behavior of green and hardened concrete. Deformed steel bars of 6 and 8 mm in diameter were used as reinforcing bars of the columns. These steel reinforcements were tested using ASTM-A615/A-615M-05a. Sika® Latex (SBR) is a modified styrene butadiene emulsion that is normally mixed with cement to form a bonding slurry. It can also be used as an additive to improve the adhesive and water resistance properties of cement and sand mortar (Laith Rasheed, 2018).

### 2.3 Soils

The specimens and R.C. column models were buried in clay soil and sandy soil (see Table 2). Two pits of dimensions 2 x 2 x 3 m, were excavated on agricultural land, located 1.5 km west of the centre of Karbala. The ground water level was 1.75 m, having properties as shown in Table 3.

#### Table 2. Soils properties (chemical and physical)

| Soil Type | SiO₂ | Fe₂O₃ | Al₂O₃ | CaO | MgO | SO₄²⁻ | Na₂O | K₂O | Cl⁻ | O.M | PH | GS |
|-----------|------|-------|-------|-----|-----|-------|------|-----|-----|-----|----|----|
| Sandy     | 18.31| 2.95  | 4.55  | 26.86| 5.87| 10.60 | 4.24 | 0.64| 1.95| 0.62| 8.1| 2.6|
| Clayey    | 33.79| 6.40  | 12.43 | 12.49| 7.79| 2.61  | 2.20 | 1.35| 0.78| 0.83| 8.3| 2.5|

#### Table 3. Ground water chemical properties

|                  | ppm     |
|------------------|---------|
| SO₄²⁻ ppm        | 4675.5  |
| Cl⁻ ppm          | 11182.5 |
| PH               | 8.45    |

### 3. Results and Discussion

Table 5 shows a decrease in the strength of all the columns with increasing concentrations of sulfate and chloride present in the clay and sandy soils.

#### 3.1 The properties of the hardened concrete

The strength compressive of columns buried in clay soil increased over time while the strength of those buried in sandy soil decreased. The tensile strength of the concrete cylinders was grown with time, something which may be due to the salt working to improve the ties between the concrete characters. Absorption increased over time, the high concentration in absorption registered for cube specimens buried in sandy soil for 240 days, an increase of 92.42%, and by 56.15% at 240 days for those buried in clayey soil. All percentages are reported in comparison with the reference cubes. It was also seen that the percentage of voids in the cubes increased with time in all mixes of polymer concrete. This was specifically the case in the polymer mix, where the increase was 80.43% in cubes buried in sandy soil and 49.64% in cubes buried in clay soil for 240 days. Table 6 provides a summary of the cube and cylinder tests (Laith Rasheed, 2018).
Table 4. Sulfates and chlorides percentage in the soils with time

| Soil Type | Salt (%) | Buried time | Time of buried (days) |
|-----------|----------|-------------|-----------------------|
| **Clay**  | Sulfate (SO₄²⁻) | 2.61 | 4.41 | 3.50 | 3.04 |
|           | Chloride (Cl⁻)  | 0.78 | 0.78 | 1.99 | 0.78 |
| **Sandy** | Sulfate (SO₄²⁻) | 10.6 | 9.5 | 9.0 | 9.6 |
|           | Chloride (Cl⁻)  | 1.95 | 1.95 | 1.24 | 1.07 |

Table 5. Results of tested column

| Group Name | Soil Type | Designation Name | Test time (days) | Cracking Load (Pc), (kN) | Failure Load (Pu), (kN) | Long. Def. (mm) | Lateral. Def. (mm) |
|------------|-----------|------------------|------------------|-------------------------|-------------------------|----------------|------------------|
| Ref.       | Clayey    | RS2              | 28               | 241.2                   | 438.48                  | 4.52           | 0.47             |
|            |           | P2               | 60               | 168.48                  | 333.36                  | 7.27           | 1                |
|            |           | P3               | 150              | 140.4                   | 349.56                  | 3              | 2.93             |
|            |           | P4               | 240              | 139.68                  | 329.04                  | 7.43           | 0.195            |
|            | Sandy     | PS2              | 60               | 194.04                  | 302.04                  | 5.25           | 0.85             |
|            |           | PS3              | 150              | 264.96                  | 350.64                  | 6.74           | 0.9              |
|            |           | PS4              | 240              | 104.4                   | 273.96                  | 2.91           | 0.7              |

Table 6. Results of Cubes & Cylinders tests.

| Group Name | Soil Type | Test time (days) | C. St. (Cub.), (MPa) | T. St. (Cy.), (MPa) | Abso. % | V. % | Dens. (Mg/m³) |
|------------|-----------|------------------|----------------------|---------------------|---------|------|---------------|
| Ref.       | Clayey    | 28               | 28.2                 | 2.2356              | 3.5865  | 8.177| 2.3472        |
|            |           | 60               | 27.547               | 2.2027              | 3.3016  | 7.4686| 2.3368        |
|            |           | 150              | 26.99                | 2.6218              | 4.7271  | 9.2128| 2.0452        |
|            |           | 240              | 30.94                | 2.921               | 5.6002  | 12.236| 2.3081        |
|            | Sandy     | 150              | 28.09                | 3.008               | 4.4502  | 9.3237| 2.1895        |
|            |           | 240              | 22.83                | 3.1911              | 6.9013  | 14.754| 2.2891        |

3.2 The impact of an aggressive solution of clay soil on polymer reinforced concrete columns

To note the impact of aggressive solution on polymer reinforced concrete columns, they were buried for 60, 150 and 240 days in clay soil to study its behavior. The first cracks in the polymer reinforced concrete columns group (Pc) were seen at the top, bottom and mid span of the columns, under applied loads of 241.2, 168.48, 140.4 and 139.68 kN for columns RS2, P2, P3 and P4 respectively. The strength of this mix decreased when buried in soil. Cracks increased and became wider with increasing loads. The columns reached their ultimate loads at 438.48, 333.36, 349.56 and 329.04 kN for columns RS2, P2, P3 and P4, respectively (See Figures 2 to 6 all marked loads must be adjusted by factor (3.6)).
Figure 2. First cracks for group Pc

Figure 3. Failure pattern for RS2

Figure 4. Failure pattern for P2

Figure 5. Failure pattern for P3
Failure occurred gradually in this group. By the final time period, deflection increase longitudinally this resulting in the columns became more ductile with time. By the end of the testing period, it was found that for the same loading values, the increase in longitudinal deflection due to an increase in ductility, except the column (P3) at test time (150 days), which it lightly enhanced in the strength than column (P2) but it still less than the reference one (RS2), these conclusions were cover by Figure 7. the lateral deflection decreases over time as seen in the Figure 8. As shown in Table 5, the cracking loads and failure loads for P2, P3 and P4 compared to RS2 are 69, 58 and 58%, and 76, 79 and 75%, respectively. This may be due to the significant effect of sulfate on the polymer mix because of large voids in the mix. These voids initially allowed sulfate to get into the concrete but, with time, interactions in the polymeric materials led to the production of molecules which worked to strengthen the concrete and raise the resistance again. The percentage of sulfate declined for those in clay soil at 150 and 240 days because of the low water table, this reducing the concentration of salts. The concrete therefore becomes stronger due to a lack of exposure to the sulfate.

Figure 6. Failure pattern for P4

Figure 7. Behaviour of Polymer R.C. column in clay soil (Load – Longitudinal Deflection)
With regard to the columns buried in clay soil, at 60 days there was no visual evidence of sulfate penetration into the columns. At 150 days, there is visual evidence of some penetration of sulfates into the polymer column to a depth of 5 cm. At 240 days, penetration can be seen up to 7 cm for the polymer column, this representing complete penetration.

3.3 The impact of aggressive solution in sandy soil on polymer reinforced concrete columns

Buried in sandy soil for 60, 150 and 240 days, the first cracks on the polymer reinforced concrete columns group (Ps), were noted at the top and bottom of the columns, under applied loads of 241.2, 194.04, 264.96 and 104.4 kN for columns RS2, PS2, PS3 and PS4, respectively. When buried in sandy soil, there was a decrease in column strength. Under increasing loads, cracks became clearer and broader. The columns reached their ultimate loads at 438.48, 302.04, 350.64 and 273.96 kN for columns RS2, PS2, PS3 and PS4, respectively. See figure 9 to 11 all marked loads must be adjusted by factor (3.6).

![Figure 9. Failure pattern for PS2](image)
A gradual failure was recorded for this group. By the end of the testing period, the longitudinal deflection had increased under a decrease in loading. The area under the curve of load-deformation also decreased meaning that the column became less toughness and had reduced ductility. These phenomena can be observed in figure 12. The polymer mix is more effected by aggressive salts in sandy soil in comparison to other mixes as its strength decreased by 37.52% at 240 days. Regarding the reinforced concrete columns, their strength increased by mid-age testing (150 days), thereafter decreasing by the end of the test time period. Figure 13 shows the lateral deflection with time at the same loadings for all columns. From table 5, it show that cracking loads and failure loads for PS2, PS3 and PS4 to RS2 are 80, 109 and 43%, and 68, 80 and 62%, respectively. The reason for this is that the polymer mix is significantly impacted by sulfate because of the large voids in the mix. These allow a larger quantity of sulfates to enter the concrete but with time, interactions within the polymeric materials lead to the production of molecules which work to strengthen the concrete raising its resistance again. The percentage of sulfates declines in sandy soil by 150 days, increasing again by day 240. This is due to the low water table reducing the concentration of salts.
Figure 12. Behaviour of Polymer R.C. column in sandy soil (Load – Lateral Deflection)

At test age 60 days, there is no penetration of sulfate inside the polymer columns. At 150 days, there was penetration to 6 cm, reaching 7 cm by 240 days.

3.4 The impact of different soils on the polymer reinforced concrete columns

In general, the columns buried in clay soil did not differ significantly in their behavior in comparison to those in sandy soil, but the differences found concerned the extent to which the compressive strength of the columns was affected by the sulfate salts found in each soil. The high sulfate and chloride content of sandy soil had more impact on the polymer mix columns. Their ductility was less than that of the
columns buried in clay soil but, the columns in clay soil had more deformation as loads increased (figures 14 to 16).

**Figure 14.** Behaviour of Polymer R.C. column in clay and sandy soil for 60 days

**Figure 15.** Behaviour of Polymer R.C. column in clay and sandy soil for 150 days
Figure 16. Behaviour of Polymer R.C. column in clay and sandy soil for 240 days

4. Conclusions

The bottom conclusions can be seen by the results of the test:

1. Ductility increases with time in polymer concrete specimens buried in clay soil but decreases in specimens buried in sandy soil.

2. The influence of exposure to contaminated soil becomes clear after 150 days of exposure. Sandy soil has more impact than clay soil on buried R.C. columns. The degree of deterioration depends on the concentration of salts.

3. The decreases in strength of polymer R.C. columns were 24.96 % for columns buried in clay soil and 37.52 % for columns buried in sandy soil, at age 240 in comparison to the reference columns.

4. Failure was gradual in the polymer R.C. columns.

5. The absorption percentage ratios increased along time in the polymer concrete specimens, where the largest value was found at 240 days age were 92.42 and 56.14 % for sandy and clayey soils respectively.

6. The ratio of voids was increased along the time for the polymer concrete cubes, the highest ratios recorded at 240 days were 80.43 and 49.64 % for sandy and clayey soils respectively.

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