Investigation the Quality of the Treatment Sand from Sulfite using Magnetic Water in Reactive Powder Concrete

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Abstract. In this study, the effect of using magnetized water in fine aggregate treatment has been investigated. Three mixtures of reactive powder concrete (RPC) were prepared and cast within two molds so that the compressive and flexure strength can be tested when the samples are cured by ordinary, autogenous, warm water and high-temperature cycles curing procedure. All of the three mixtures consisted of the same primary material; the difference was in the sulfite content of the fine aggregate, where the intended sand samples have diverse sulfite content. The first mixture’s sulfite content was limited within the Iraqi specifications No.45/1984, and it was equal to 0.13%, the second mix contained sand with high sulfite content of 3.54%, and in the third; the latter sand was washed with magnetizing water before mixing. The test results pointed out a severe decrease in RPC properties when the high sulfite sand was used by taking the low sulfite content mixture as a reference mix. A decrease was recorded in the compressive strength by 8.6% and 16.8% when the samples were tested at the age of 28-days and 90-days, respectively, and cured with ordinary curing procedures. Similarly, the flexure strength decreases by 7.1% and 13.5% when the samples are tested at the age of 28-days and 90-days, respectively, and cured with an ordinary curing procedure. This decrease in RPC strength could be recovered, as the third mixture’s test results indicate; when the sand was treated with magnetized water before mixing, and the sulfite content was reduced down to (0.274%) accordingly.

Keywords. Reactive powder concrete, Sulfite content, Magnetic water, Magnetize water, RPC improvement, Curing technics.

1. Introduction

Reactive powder concrete (RPC) is a new type of concrete with high strength and good durability [1]. In any concrete mixture, the sulfite attack could severely affect its mechanical properties, especially in Iraq. One of the essential issues with concrete mixtures is the high possibility of sulfite attack due to its high sand [2]. This problem can lead to decreasing in concrete compressive strength gradually with aging. Furthermore, a future internal cracking is expected by using this kind of sand with a concrete mixture [3]. The calcium sulfate (gypsum) is assumed to be the most dangerous form of this attack. In the Iraqi sand, the gypsum percentage to the total sulfite content is about 95% [4]. Thus, this problem should be considered in any kind of mixtures.

The magnetized water is produced by letting the normal water passes through magnetic treatment devices (MTDs), as shown in Figure 1.
The water properties are affected by this process; the hydrogen bond shown in Figure 2 [6] in water molecules will be broken, and the water clusters will be arranged in a different order, as shown in Figure 3. Accordingly, water stability, viscosity, and activity will be increased [7], and its surface tension will be decreased [8]. This change in water molecules and properties could increase sand treatment effectiveness to extract the sand’s sulfite and reduce its content, as this paper aims to investigate.

As stated by [9], to increase RPC mechanical properties by using the same material dosage, a heat curing should be applied. Consequently, four different curing procedures were implemented in this work, i.e., ordinary curing technic, autogenously curing, warm water curing, and high-temperature
water curing. Several researchers studied the influence of sulfite content in concrete and how to overcome this problem as follow:

Al-Hubboubi et al. [10]; investigated reducing sulfite content in sand utilized in the concrete mixture. The treatment was conducted by using magnetized water in washing the fine aggregate. The investigation found that when the treated sand (containing $SO_3\% = 0.25$) within the concrete mixture, its compressive strength increased by (7.14, 10.69, and 32.87)% at (28, 90, and 180 days), respectively, comparing it with the concrete mixture that was mixed with the same sand before washing, which has sulfite content of ($SO_3\% = 3$). Capraro et al. [11] studied the internal sulfite attack in cement pastes and mortar when a different pyrite dosage was added to the mixtures. In this study, Pozzolanic cement was utilized (65% Portland cement and 35% fly ash). The samples were cured for 28-days to determine samples’ strength; axial compression and tensile strength tests were conducted. The researchers concluded that; as pyrite contamination goes higher, the effect of sulfite on the mechanical properties decreases. Saleh [12] investigate the effect of external and internal sulfite on the concrete compressive strength. The work included 360 concrete cubes with different water-cement ratios; 10% of silica fume was added to the concrete mixture of this study, and two types of sand were used. With $SO_3=0.2$% and the second with $SO_3=1.13$%, the samples were divided into two groups; the first group was submerged in water with dissolved sulfate ($SO_3=6965$ ppm), the second group was immersed in normal water. The results indicated that the effect of internal sulfite was noticed, especially in the mixture containing sand with $SO_3=1.13$%, this influence could be reduced when 10% silica fume was added to the mixtures and a 0.45 water/cement ratio was adopted. Al-Galawi [13] studied the effect of using sulfate-resisting Portland cement SRPC instead of ordinary Portland cement OPC to reduce the bad influence of internal sulfite attack and if the mineral admixture (silica fume SF and high reactivity metakaolin HRM) is used to produce a high-performance concrete HPC. The investigated percentage of sulfite was (1, 2, and 3) %. The experimental test results pointed out a less reduction in the tested properties when the SRPC is used at all age of the tests, and the HRM is better in resisting the sulfite attack than the SF in both types of cement. The effect of curing technic on RPC strength was investigated by [14]. The work indicated an enhancement by 41.9%, 36.9%, and 38.4% in the compressive strength, modulus of rupture, and splitting tensile strength, respectively, which is achieved when the samples are cured with high-temperature water (90°C). The previous study showed that it is crucial to find a solution to the sulfite in the fine aggregate. Therefore, in this study and to reduce the sulfite content in the fine aggregate, magnetize water was used to wash fine aggregate and its influence in RPC strength at all ages with different curing procedures.

2. Experimental work

2.1. Program

Three mixtures of RPC were prepared and cast into 24 samples to achieve the scope of this study, the specimens were categorized by their mixtures into three groups, where in the first group, the fine aggregate being used is within the Iraqi specifications No.4/1984 [15], i.e., low sulfite content (LSC), and in the second group, the fine aggregate has high sulfite content (HSC) equal to 3.54%, which was used directly without washing. On the other hand, the sand utilized in the third group was washed with magnetizing water before mixing, i.e., the group was named treated sand (TS). The same material dosage of cement, silica fume, superplasticizer, fine aggregate, and steel fibers were utilized in the three groups. The mixtures were cast into two types of molds, i.e., cubic and prism, to indicate the compressive and flexure strength. Furthermore, four different curing procedure has been carried out after casting to investigate its influence into improvement RPC strength of the groups above, i.e., ordinary curing, autogenous curing, high-temperature cycle curing, and warm water curing.

2.2. Materials

2.2.1. Ordinary portland cement OPC. Table 1 and Table 2 below present the physical and chemical results of the tested cement that are used in this study, respectively. The results of the two tests have concurred with the Iraqi specifications No.5/184 [16] and ASTM C150-12 specifications [17].
Table 1. (O.P.C) Physical properties.

| Physical properties | Test results | Iraqi Requirement No. 5/1984 | ASTM Requirement C150-12 |
|---------------------|-------------|-------------------------------|--------------------------|
| The area of specific surface (Blaine method) (m²/kg) | 290 | ≥ 230 | ≥ 280 |
| The soundness % (Autoclave Method) | 0.03 | ≤ 0.8 | - |
| The time of setting (Vicat’s method) | | | |
| Initial setting (min.) | 110 | ≥ 45 min | ≥ 45 min |
| Final setting (min.) | 285 | ≤ 600 min. | ≤ 375 min. |
| The compressive strength (MPa) | | | |
| After three days | 23 | ≥ 15 | ≥ 12 |
| After seven days | 29 | ≥ 23 | ≥ 19 |

Table 2. Chemical composition and main compounds of cement.

| Oxide Composition | Abbreviation | Percentage by weight | Iraqi Requirement No. 5/1984 | ASTM Requirement C150-12 |
|-------------------|--------------|----------------------|----------------------------|--------------------------|
| Lime | CaO | 60.5 | - | - |
| Iron Oxide | Fe₂O₃ | 4.9 | - | - |
| Alumina | Al₂O₃ | 5.91 | - | - |
| Silica | SiO₂ | 18.64 | - | - |
| Sulfite | SO₃ | 2.38 | ≤ 2.5% | ≤ 3.0% |
| Magnesia | MgO | 3.24 | ≤ 5.0% | ≤ 6.0% |
| Insoluble residue | I.R. | 0.55 | ≤ 1.5% | ≤ 0.75% |
| Loss on ignition | L.O.I. | 2.42 | ≤ 4.0% | ≤ 3.0% |
| Main Compounds | | | | |
| Tri Calcium Silicate | C₃S | 48.35 | - | - |
| Tetra calcium Aluminate-Ferrite | C₄AF | 15.62 | - | - |
| Di-Calcium Silicate | C₂S | 20.56 | - | - |
| Tri Calcium Aluminate | C₃A | 4.93 | - | - |

2.2.2. Fine aggregate. Table 3 below presents the physical test results for the sand samples used in this work and its comparison with the Iraqi specifications No.45/1984 [15]. Furthermore, the sulfite content of the washed and the unwashed sand samples are highlighted.

Table 3. Physical tests result in the fine aggregate and its sulfate content.

| Sieve size (mm) | 1st sample passing by weight % | 2nd sample without washing (HSC) passing by weight % | 3rd sample after treatment (TS) passing by weight % | Iraqi Requirement No. 45/1984 (Zone 4) |
|-----------------|------------------------------|--------------------------------|--------------------------------|--------------------------------|
| 10 | 100 | 100 | 100 | 100 |
| 4.75 | 100 | 100 | 100 | 95-100 |
| 2.36 | 100 | 100 | 100 | 95-100 |
| 1.18 | 100 | 100 | 100 | 90-100 |
| 0.6 | 83.62 | 89.1 | 89.1 | 80-100 |
| 0.3 | 38.3 | 31.7 | 31.7 | 15-50 |
| 0.15 | 9.62 | 5.7 | 5.7 | 0-15 |
| Fineness modulus | 1.9 | 2.1 | 2.1 | - |
| Sulfite content % | 0.13 | 3.54 | 0.27 | Max. 0.5 |
| Specific gravity | 2.65 | 2.64 | 2.64 | - |
| Absorption percentage | 1.02 | 1.04 | 1.04 | - |

2.2.3. Steel fibers, silica fume, and superplasticizer. In this study, the adopted steel fibers were straight type brass coating with a length of 13mm and diameter equal to 0.2mm. The steel fibers’ tensile
strength was 2600MPa, as specified by the manufacture. On the other hand, a micro-silica 920D was added to the RPC mixture. The used silica fume was tested in building a research directorate, according to ASTM C1240 [18]. Table 4 below shows that the test results have a good agreement with the required specifications. Furthermore, to increase the water effectiveness in the RPC mixture [19], a superplasticizer of type Hyperplastic PC 600 was used in this study.

2.3. Sand washing
The intended fine aggregate with a sulfite content (SO₃ = 3.54\%) was set into a container, as shown in Figure 4, and placed in the treatment station shown. However, the treatment process begins by opening the water valve so that the water runs into the MTD, producing magnetized water that brick through the sand sample and washing it by taking a high percentage of slag and sulfite as reported earlier in the tested sand (washed and unwashed samples) of Table 3., i.e., the obtained sulfite content in the washed sand was (SO₃ = 0.274\%). The treatment test outlines and its results with different sand: water ratio is presented in Figure 5. It should be mentioned that the best results were obtained with sand: water ratio equal to 1:10. This ratio was adopted in the treatment process for all sand.

| Test No. | Samples weight (kg) | Amount of water used (Litter) | Sand: water ratio | Sulfite contain in the sand before treatment SO₃ (%) | Water TDS* before washing | Sulfite contain in the sand after treatment SO₃ (%) | Water TDS After washing |
|----------|-------------------|-----------------------------|------------------|---------------------------------|--------------------------|---------------------------------|--------------------------|
| 1        | 1                 | 12                          | 1:12             | 1.753                           | 1093                     | 0.776                           | 869                      |
| 2        | 1                 | 20                          | 1:20             | 0.776                           | 869                      | 0.697                           | 1656                     |
| 3        | 20                | 160                         | 1:8              | 0.697                           | 1656                     | 0.274                           | 1347                     |
| 4        | 20                | 200                         | 1:10             |                                |                          |                                 |                          |

*TDS: Total dissolved solids in water
2.4. Mixture
The adopted materials dosages are presented in Table 7, driven based on [20] study and trail mix conducted in this work.

| Material            | Weight (kg/m³) |
|---------------------|----------------|
| Cement              | 1100           |
| Silica fume         | 10% replacement by mass of cement |
| Steel fibers        | 156            |
| Fine aggregate      | 1100           |
| Water               | 209            |
| Hyperplastic PC 600 | 23             |

Table 7. Mixing material content.

The mixing procedure in this study was conducted according to [20] recommendations as follow:
- Firstly, the cement and silica fume were mixed according to [20] specifications and blend for three minutes in the 0.3m³ mixer shown in Figure 6 below.
- After that, the fine aggregate was added, and the mixing is carried on for five minutes,
- Next, small amounts of water and the superplasticizer were poured into the mixer for three minutes, and after that, the material mixing continued for five minutes,
- The final step was adding the steel fibers, where it was inserted in patches for three minutes. To ensure the mixture homogeneity, the mixing process continues after adding all the required materials for not less than two minutes, as shown in Figure 7.

![Figure 6. The adopted mixer used in this study.](image)

![Figure 7. RPC material mixing.](image)

2.5. Samples preparations
As stated earlier, the compressive and flexure strength of the RPC was investigated. Therefore, two types of molds, which are cubic and prism, have been used to achieve the objective of this study, as shown in Figure 8. The compressive strength can be tested based on [21], and the flexure strength can be indicated according to [22].

![Figure 8. The used molds in this study.](image)
2.6. Curing

Four kinds of curing procedures were conducted in this study, the influence of each technique on the RPC strength was tested, and the improvement percentage was reported.

2.6.1. Ordinary curing (OC). In this procedure, the ASTM C192 [23] was adopted in curing the RPC samples, as shown in Figure 9. The specimens were submerged in a water tank that has a temperature same as room temperature. The curing continues until the testing day, after either 7, 28, or 90 days.

![Figure 9. Ordinary curing by water immersion.](image)

2.6.2. Autogenously curing (AC). In this technique, the ASTM C684-99 [24] was implemented. Before sending the samples to the water tank, it was covered by burlap and polythene, as shown in Figure 10, immediately after casting for two days.

![Figure 10. Covering the RPC samples with burlap and polythene (Autogenously curing).](image)

2.6.3. Warm water curing (WC). The ASTM C684-99 [24] was used in this curing technique. However, the samples were immersed in 35°C water temperature after casting by 24hr, as shown in Figure 11.

![Figure 11. Warm water curing.](image)

2.6.4. High-temperature cycles (HC). In this procedure, the ACI 517.2R-92 [25] was adopted. Accordingly, the RPC samples were put in a water bath after casting by 24hr; as shown in Figure 12, the water temperature was increased by 20°C/hour until it reached 70 °C. At this temperature, the
status steads still for five hours; after that, a decrease by 20°C/hour was applied until the water temperature reached the 20°C, and as such, that temperature was fixed for five hours also. The cycles of increasing and decreasing water temperature were repeated for three days; the samples were immersed in a water tank similar to the OC procedure mentioned above.

**Figure 11.** Warm water (35°C) submerge.  
**Figure 12.** Submerge in high-temperature water.

3. Results and discussions

A degradation in the strength is expected due to the high sulfite content in some specimens, due to the mineral oxidation phenomenon causes internal expansion and cracks in the high level of sulfite [26]. The compressive strength test results are presented in Table 8 below at the ages of 7, 28, and 90-days, respectively.

| Mixture description | Curing procedure | Compressive strength (MPa) |
|---------------------|------------------|---------------------------|
|                     | Description      | Abbreviation  | 7-days | 28-days | 90-days |
| RPC mixed with      | Ordinary curing  | OC            | 84.81  | 99.21   | 102.92  |
| Normal Sand has low | Autogenous curing | AC           | 95.22  | 110.34  | 113.25  |
| sulfite content (LSC)|                   |              |         |         |         |
|                     | Warm water curing | WC           | 110.44 | 124.11  | 127.41  |
|                     | High temp cycle  | HC            | 112.24 | 127.81  | 130.32  |
| RPC mixed with sand | Ordinary curing  | OC            | 84.27  | 90.63   | 85.68   |
| that has high sulfite| Autogenous curing | AC           | 94.32  | 100.37  | 93.91   |
| content (HSC)       |                   |              |         |         |         |
|                     | Warm water curing | WC           | 109.68 | 112.89  | 105.79  |
|                     | High temp cycle  | HC            | 111.30 | 115.33  | 107.72  |
| RPC mixed with      | Ordinary curing  | OC            | 83.97  | 99.40   | 102.25  |
| treated sand (TS)   | Autogenous curing | AC           | 96.03  | 111.17  | 113.84  |
|                     | Warm water curing | WC           | 111.37 | 124.97  | 126.86  |
|                     | High temp cycle  | HC            | 112.83 | 126.79  | 131.26  |

Based on the results indicated in Table 8, at an early age at 7-days, the effect of sulfite content in the HSC group is insignificant, which is compatible with the findings of [27] [28] finding. In comparison, a negative outcome in compressive strength at the age of 28-day can be noticed. After the age of 28-day until 90-day, the effect of sulfite contents becomes more severe and needs to be considered. Its decrease percentage reached (17.34%) compared to the LSC group- reference mix at 90 days. So, washing process treatment with magnetized water provides a good solution to treat high sulfite content in sand. After using treated sand in third group mixes, it shows optimistic results, as shown in Figure 13 to 16, by comparing it with the first LSC group strength compatible with [10], when it is cured with OC, AC, WC, and HT procedures, respectively.
Figure 13. Compressive strength changing percentage due to using HSC or TS, when the samples are cured by OC.

Figure 14. Compressive strength changing percentage due to using HSC or TS, when the samples are cured by AC.
Figure 15. Compressive strength changing percentage due to using HSC or TS, when the samples are cured by WC.

Figure 16. Compressive strength changing percentage due to using HSC or TS, when the samples are cured by HC.

Figure 17 to 19 show the enhancing percentage due to conducting different curing procedures instead of the ordinary curing one for the LSC, HSC, and TS groups. The effect of choosing a unique curing procedure has a remarkable effect on the RPC compressive strength. An increase of 32.34%, 28.83%, and 26.62% could be achieved when the high temperature cycle procedure is adopted instead of the ordinary curing procedure. The samples are tested in the age of 7, 28, and 90-days, respectively.
Figure 17. RPC compressive strength improvement when different curing procedure is applied instead of the ordinary curing for LSC group.

Figure 18. RPC compressive strength improvement when different curing procedure is applied instead of the ordinary curing for HSC group.

Figure 19. RPC compressive strength improvement occurs when different curing procedures are applied instead of the ordinary curing for the TS group.
The test results of RPC flexure strength for all groups, and the different curing procedures are presented in Table 9 below.

### Table 9. RPC Flexure strength tests results.

| Mixture description                  | Curing procedure | Flexure strength (MPa) |
|--------------------------------------|-----------------|------------------------|
|                                      | Description     | Abbreviation | 7-days | 28-days | 90-days |
| RPC mixed with Normal Sand has low sulfite content (LSC) | Ordinary curing   | OC          | 17.78   | 19.93   | 21.09   |
|                                      | Autogenous curing| AC          | 19.87   | 22.05   | 23.16   |
|                                      | Warm water curing| WC          | 22.64   | 24.68   | 25.67   |
|                                      | High temp cycle  | HC          | 23.02   | 25.19   | 26.58   |
| RPC mixed with sand that has high sulfite content (HSC)   | Ordinary curing   | OC          | 17.56   | 18.52   | 18.22   |
|                                      | Autogenous curing| AC          | 19.54   | 20.40   | 19.93   |
|                                      | Warm water curing| WC          | 22.28   | 22.85   | 22.11   |
|                                      | High temp cycle  | HC          | 22.66   | 23.32   | 22.89   |
| RPC mixed with treated sand (TS)     | Ordinary curing   | OC          | 17.52   | 19.86   | 21.21   |
|                                      | Autogenous curing| AC          | 19.92   | 22.17   | 23.14   |
|                                      | Warm water curing| WC          | 22.74   | 24.52   | 25.61   |
|                                      | High temp cycle  | HC          | 23.11   | 25.36   | 26.66   |

The effect of high sulfite content on flexure strength does not appear significant at the early age of 7 days, as stated earlier with compressive test results. However, at the age of 28-day until 90-day, the effect of the sulfite contents becomes more serious that needs to be considered. A 13.9% decreasing percentage has been recorded at the age of 90-days when the high sulfite sand is used within the RPC mixture. By using MW in sand treatment, this influence was overridden, as shown in Figure 20 to 23.

![Figure 20](image-url)  
**Figure 20.** Flexural strength changing percentage due to using HSC or TS, when the samples are cured by OC.
Figure 21. Flexural strength changing percentage due to using HSC or TS, when the samples are cured by AC.

Figure 22. Flexural strength changing percentage due to using HSC or TS, when the samples are cured by WC.
Figure 23. Flexural strength changing percentage due to using HSC or TS, when the samples are cured by HC.

For all groups, using different curing procedures also has a good influence on the RPC flexure strength, as shown in Figure 24 to 26. The enhancing percentage in the RPC flexure strength could reach 26.36%, 25.92%, and 27.69% if a high-temperature cycle curing procedure is used instead of the ordinary curing procedure and tested at the age of 28-day for the LSC, HSC, and TS groups, respectively.

Figure 24. RPC flexure strength improvement when different curing procedure is applied instead of the ordinary curing for LSC group.
Figure 25. RPC flexure strength improvement when different curing procedure is applied instead of the ordinary curing for HSC group.

Figure 26. RPC flexure strength improvement when a different curing procedure is applied instead of the ordinary curing for the TS group.

4. Conclusions
The experimental tests result of this study, outcomes with the following conclusions;

- Using fine aggregate with a high sulfite content passing the Iraqi specifications negatively influences the reactive powder compressive and flexure strength. The compressive strength decreases by (9\(\pm\) 0.8) % and (17\(\pm\)0.5) % at the age of 28 and 90 days, respectively, and the flexure strength decreases by (7.3\(\pm\) 0.2) % and (13.7\(\pm\)0.2) % at the age of 28 and 90 days, respectively.

- In the first ages of 7-days, the sulfite effect did not appear clearly either in compressive or flexural behavior, but after this age and as the samples reached the age of 28-days, a noticeable decrease in the mechanical properties reported.

- Magnetized water could be used in washing fine aggregate that has a high sulfite content. The washing process with MW could extract a considerable amount of sulfite. In this study, the reduction in the sulfite content reached 57%.
The RPC samples that included treated sand showed stiffness similar to the samples that were made using low sulfite content sand. i.e., the washing process eliminates the negative sulfite effect in the RPC mechanical properties.

The curing procedure could increase the RPC mechanical properties, where the compressive strength could increase them by 11.22%, 25.1%, and 28.83%, when the samples are tested at the age of 28-day and cured with AC, WC, and HC procedures, respectively, instead of the OC procedure. The flexure strength could be increased by 10.64%, 23.83%, and 26.39% when the samples are tested at the age of 28-day and cured with AC, WC, and HC procedures, respectively, instead of the OC procedure. However, the best enhancement in the RPC properties is achieved by using the high-temperature cycles procedure.

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**Acknowledgments**

The authors would like to thank the Civil Engineering Department at the University of Baghdad and the Building Research Directorate for providing all the required facilitation and instruments for conducting this study.