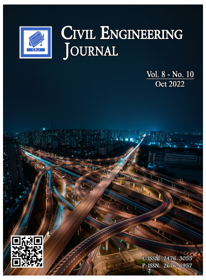
Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 8, No. 10, October, 2022



Ultimate Load of Different Types of Reinforced Self-Compacting Concrete Columns Attacked by Sulphate

N. Muhammed [1*], L. Shihab [2], S. Sakin [2]

[1] *Water Resources Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq.*

[2] *Civil Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq.*

Received 24 June 2022; Revised 07 September 2022; Accepted 21 September 2022; Published 01 October 2022

Abstract

In this study, the effects of the partial immersion of sulphate attack on the ultimate load capacity of reinforced self-compacting concrete (SCC) columns and the sulphate attack resistance improvement using silica fume, steel fibres, and the combination of silica fume and steel fibres were assessed. Twelve short circular self-compacting reinforced concrete columns (0.150 m in diameter and 0.7 m long) were cast and divided into groups according to (1) the three acid-attack groups. The first group was tested without an acid attack (control). The second group was tested after 1 month of exposure to 2% acid. The final group was tested after 1 month of exposure to 4% acid and was then (2) subdivided according to the type of casted concrete. The first group was cast with SCC. The second group was cast with SCC and silica fume (0.1% of the cement weight). The third group was cast with SCC and 1% volume fraction steel fibres. The fourth group was cast with SCC silica fume and 1% volume fraction steel fibre. All columns were tested by axial loading. The ultimate load was increased by 42% with silica fume, 190% with steel fibres, and 238% with silica fume and steel fibres. Exposure to 2% and 4% acid reduced the ultimate loads of the columns casted with SCC by 23% and 47%, the columns casted with SCC and silica fume by 34% and 37%, the columns casted with SCC and steel fibres by 69% and 78%, and the columns casted with SCC, silica fume, and steel fibres by 72% and 79%, respectively. Based on the results, using silica fumes improved sulphate resistance, and using steel fibres enhanced sulphate resistance at an acceptable ratio. Furthermore, the mix with silica fume and steel fibres improved sulphate resistance at a good ratio. We encountered several problems in this study. The partial immersion of sulphate affected the strain in both concrete and steel. Future studies using different immersion ratios are recommended.

Keywords: Reinforced Concrete; Sulphate Attack; Partially Immersing in Sulphate; Self-Compacting Concrete; Steel Fibre; Silica Fume.

1. Introduction

Self-compacting concrete (SCC) is a developed concrete that does not require vibration for casting and compacting. Most SCC mixes, including limestone powder (LP), which improves workability and strength development, are widespread in Iraq. Durability is an important aspect of concrete, especially when it has to resist different types of chemicals. Durability mainly depends on the materials used in the concrete. Recently, the durability of concrete has been improved by adding different materials, such as LP, silica fume, or steel fibres [1].

SCC is increasingly used, especially in precast concrete, for many applications, including sewer pipes, foundations, and many other concrete members with narrow sections, such as columns, or any other members where durability is essential because reducing porosity improves steel protection. Furthermore, casting is simple without the use of a vibrator [2].

---

* Corresponding author: nura_jacob@uomustansiriyah.edu.iq

http://dx.doi.org/10.28991/CEJ-2022-08-10-04

Concrete can be attacked by different acids, and sulphuric acid is an extremely strong acid that can severely damage concrete members. This acid is naturally produced in soil and groundwater [3, 4]. Members of concrete structures can also be attacked by groundwater and chemical wastes that contain sulphur-oxidizing compounds [5]. Structural members, such as columns, can be corrupted by sulphuric acid in cases of leaks in sewer pipes [6]. Protection against sulphate attacks requires a reduction in the permeability of concrete, where low permeability can increase its durability when exposed to severe conditions [7-9].

Concrete must be protected and kept consistently safe to reduce damage when concrete is attacked by sulphate, and a way to perform this is to use SCC. Usually, silica fume is used to reduce the permeability of concrete. The use of steel fibres can also affect concrete permeability [10-12]. Other methods used to reduce the damage caused by sulphate penetration into concrete have been studied; one of these methods is CFRP confinement [13]. The use of CFRP confinement decreases the reduction in initial axial stiffness and load-carrying capacity. In addition, it reduces the ultimate axial displacement. All of the above changes have been studied using different numbers of wet–dry cycles for different durations.

Anwar & Makhlouf [14] used nine different concrete mixtures with 15–25% fly ash. They also studied their effects on the properties of concrete and sulphate-resisting cement by using different water/binder material values at 0.4, 0.5, and 0.6 cured in water for 28 days, immersed in a 5% sodium sulphate solution for 6 months, and then tested by destructive and non-destructive tests. They found that using fly ash enhanced the resistance of concrete to sulphate attacks. Selvan [15] demonstrated the effect of the change in Portland cement components on sulphate attack resistance. Four types of cements with different components (i.e., ordinary Portland cement, sulphate resistance cement, pozzolana Portland cement, and Portland slag cement) were exposed to two different sulphate attack methods (i.e., wet and dry cycles and complete immersion). The results showed that Portland slag cement has good sulphate resistance, and the specimens exposed to the wet and dry cycles deteriorate more rapidly than the completely immersed specimens.

Bektimirova et al. [16] showed that reactive powder concrete exhibits good sulphate resistance by analyzing the different mixtures of reactive powder concrete attacked with different sodium sulphate concentrations. Rasheed et al. [17] stated that the use of the polymer in reinforced concrete subjected to sulphate salt attack is not advisable. They found that the polymer negatively affects the strength of reinforced concrete by studying the compressive strength of polymer-reinforced columns with a 7.5% polymer/cement ratio immersed in different sulphate-concentrated soils (SO_3: 10.609% and 2.61%) for various durations.

The abovementioned studies have focused on the effect of sulphate attack on specimens either fully immersed in sulphate water and soil or exposed to wet and dry cycles. To the best of our knowledge, no study has dealt with the use of steel fibres or the mix of steel fibres and silica fume on the sulphate resistance of partially immersed concrete columns. Thus, this study investigated the column behavior cast with SCC and different admixtures subjected to sulphate attacks.

2. Research Significance

In this research the sulfate resistance of twelve reinforced self- compacting concrete columns was studied. The casted columns were divided mainly in to three groups, the first group tested without exposure to sulfate acid (control). The second group was tested after partial immersion (a quarter of the column from the bottom) in 2% sulphate acid concentrate for 30 days. Finally, the third group was tested after partial immersion (a quarter of the column from the bottom) in 4% sulphate acid concentrate for 30 days.

Each group was subdivided into four SCC columns (i.e., control without silica fume or steel fibres, with silica fume at 10% of cement weight, with 1% steel fibres volume and with mono of silica fume at 10% of cement weight and 1% steel fibres volume).

All specimens were tested under static load using the MFL system of the hydraulic test machine type EPP 300. Given the limited number of specimens, a simple analysis was conducted using the Excel program to compare them with each other. Figure 1 shows a flowchart of the research methodology.

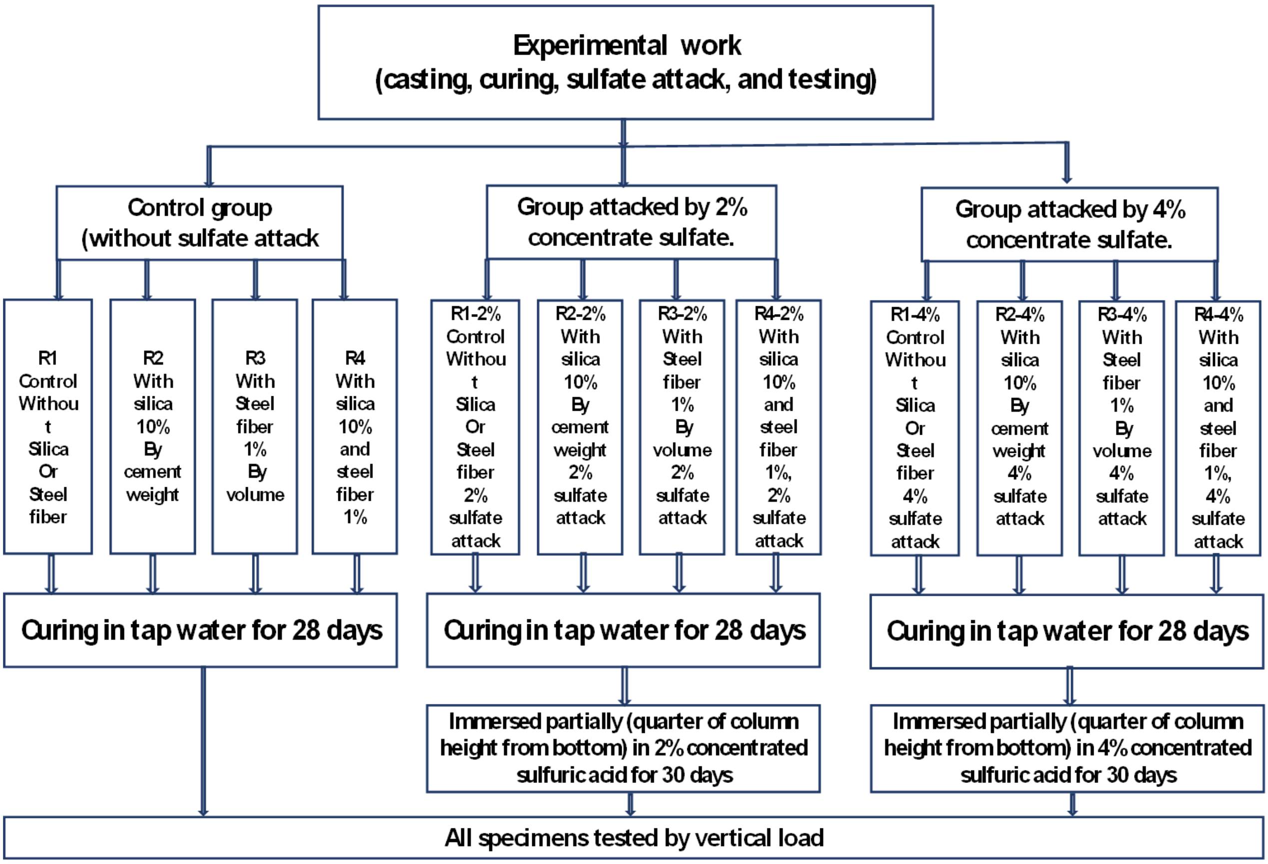


Figure 1. Flowchart of the research methodology

3. Materials and Methods

3.1. Materials

All materials met the specification limits for concrete: ordinary Portland concrete, sand, crushed 10 mm maximum-sized gravel, tap water, silica fume and steel fibres with a density of 7,800 kg/m^3, diameter of 0.2 mm and length of 15 mm. All material properties are shown in Tables 1 to 5, and the graded curves are shown in Figures 2 and 3. The steel reinforcement bars were composed of six deformed bars (6 mm longitudinally and 4 mm stirrups at 100 mm c/c). The cover of the concrete was 20 mm from the top, bottom and sides of the columns.

Table 1. Analysis of physical properties of cement

Property	Result	I.O.S 5/1984
Fineness by air permeability	3012	Not less than 2300 cm^2/gm
Method (Blain)		
Initial setting time	140 min	Not less than 45 min.
Final setting time	4.2 hr	Not more than 10 hrs
Compressive strength	33	Not less than 15 MPa
3-day age	45	Not less than 23 Mpa
7-day age		

Table 2. Limestone powder chemical analysis

Oxide	Content %
CaO	57
SiO_2	1.4
Fe_2O_3	0.1
Al_2O_3	0.68
MgO	0.12
SO_3	0.23
L.O.I	4.7

Table 3. Analysis of chemical properties of cement

Oxides	Content %	Iraqi Specification Limits I.S.O 5/1984
CaO	63.46	60%-67%
SiO_2	19.94	17%-25%
Al_2O_3	4.67	3.0%-8.0%
MgO	2.86	5% max.
Fe_2O_3	3.29	0.5-6.0
SO_3	2.3	2.8% max.
L.O.I	3.32	4% max.
Insoluble Residue	0.72	1.5% max.
L.S.F.	0.97	0.66-1.02
Compound composition		
C_3S	39.28	
C_2S	32.63	
C_3A	11.98	
C_4AF	8.00	

Table 2. Steel fibres properties

Fibres diameter	0.2 mm (+/- 0.02)
Fibres length	15 mm (+/-1)
Tensile strength	2460 MPa
Modulus of Elasticity	200 GPa
Density	7.5 g/cm^3
Shape	Straight
Apperance	Shiny, brass coated
Safety	Non Toxic, Non Irritating, Neutral

Table 3. Silica fume properties

SiO_2 Content	>85%
Alkaline as Na_2O	<1.5%
Loss on ignition	<4%
Moisture content	<3%
Specific surface area	>15 m^2/g

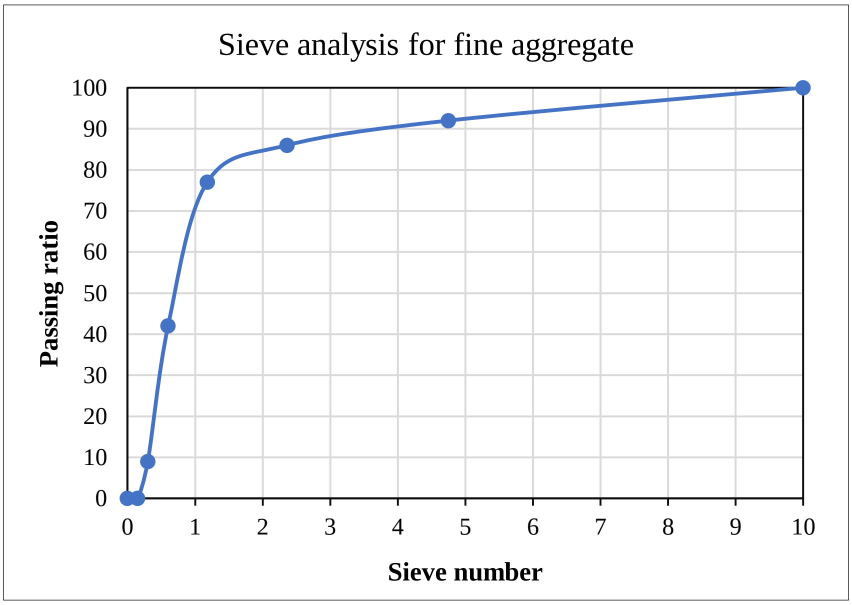


Figure 2. Sieve analysis grading curve for fine aggregates

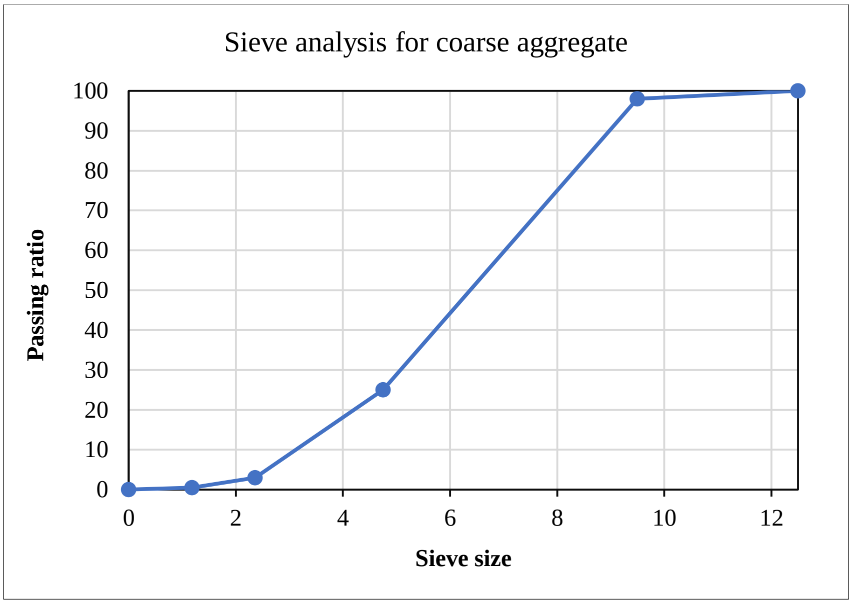


Figure 3. Sieve analysis grading curve for coarse aggregates

3.2. Casting and Curing

Twelve columns with a diameter of 150 mm and height of 700 mm were divided into three groups and cast using a plastic mould. The columns were first reinforced with steel bars and then cast vertically. The first group of columns was made with SCC. The second group was made with SCC and silica fume (the silica fume used was 10% of the cement weight). The third group was made with SCC and 1% steel fibres volume. Finally, the fourth group was made with SCC, silica fume and 1% steel fibres volume. The optimum ratio for silica fume is 5%–10% of cement weight and 1%–1.5% of steel fibres volume, especially when they are combined [12]. The details of all specimens are shown in Figure 1 (flow chart) and Table 6. The surfaces of the columns were adjusted and modified using a healer. The mould was removed after 24 h, and the columns were cured in water for 28 days.

Table 4. Specimen details

Symbol	Description
SCC	Self Compacted Concrete
R1	SCC control column
R2	SCC+10% by cement weight silica fume column
R3	SCC+1% by volume steel fibres column
R4	SCC+10% by cement weight silica fume+1% by volume steel fibres column
R1-2%	SCC column exposure to 2% concentrate sulfate
R2-2%	SCC+10% by cement weight silica fume column exposure to 2% concentrate sulfate
R3-2%	SCC+1% by volume steel fibres column exposure to 2% concentrate sulfate
R4-2%	SCC+10% by cement weight silica fume+1% by volume steel fibres column exposure to 2% concentrate sulfate
R1-4%	SCC column exposure to 4% concentrate sulfate
R2-4%	SCC+10% by cement weight silica fume column exposure to 4% concentrate sulfate
R3-4%	SCC+1% by volume steel fibres column exposure to 4% concentrate sulfate
R4-4%	SCC+10% by cement weight silica fume+1% by volume steel fibres column exposure to 4% concentrate sulfate

3.3. Steel Reinforcements

All columns have the same reinforcement ratio and distribution (6 bars: 6 mm longitudinally and 4 mm c/c 100 mm stirrups). All bars were deformed type. The steel reinforcement details are shown in Figure 4.

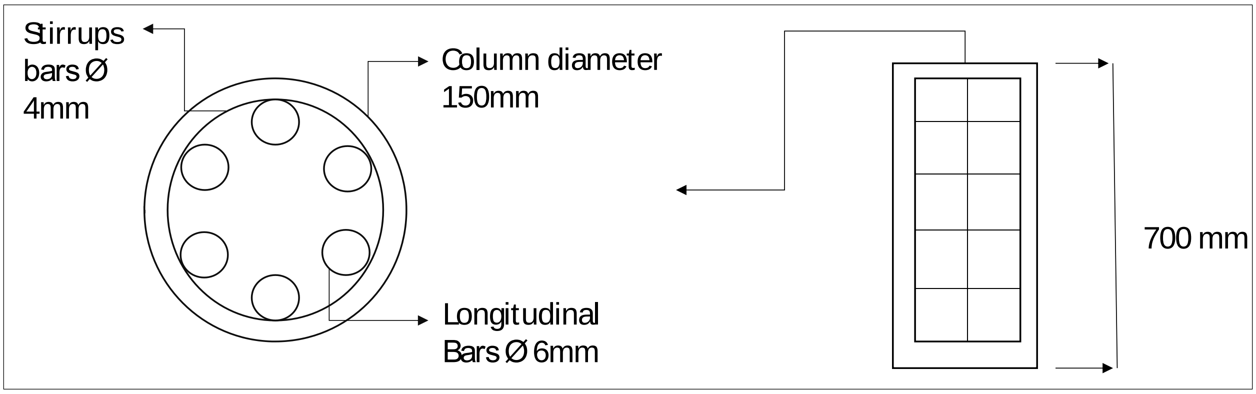


Figure 4. Steel reinforcement details

3.4. Sulphate Attack

After 28 days of curing, the columns were extracted from the water basins and then placed in special plastic tanks containing two different concentrations (2, and 4%) of sulphate acid solutions and a tank containing the control samples (Figure 5). The height of the acid solution level in the basin was equal to the height of the quarter of the column from the bottom, as shown in Figure 4. Thus, the columns remained in these basins for 30 days and were then extracted and tested. The control specimens R1, R2, R3 and R4 were not exposed to sulphate attack. However, after 28 days of curing, they were kept inside the laboratory until the day that all specimens were tested.

Figure 5. Sulphate immersion

3.5. Test Method

All columns were tested using a static vertical load subjected to the MFL system of the hydraulic test machine type EPP 300. The deflection at the middle–top part of the column was measured using a dial gauge. The strain of the concrete and steel could not be tested because of the effect of the sulphate on the surfaces where the locally available strain gauges were placed. The column testing failed. Figure 6 shows the test method setup.

Figure 6. Test method

4. Results and Discussion

4.1. Load–Deflection Relationships

For all specimens, deflection was measured at the middle of the effective length of the columns using a dial gauge (accuracy 0.01 mm). Furthermore, in this work, we focused on the strength of the columns after exposure to acid attack.

4.1.1. Group 1 (R1, R2, R3 and R4)

Figure 7 demonstrates the load–deflection relationship of the control group. For this group, the behavior of all columns is ductile, starting with a linear style before the appearance of the first crack and then completing with a ductile style to the failure phase. In the failure phase, some stiff behavior has appeared in R3, which contains steel fibres due to the addition of this material to the SCC. All other columns showed the same behavior, except for the ultimate loads, which depend on the types of admixtures.

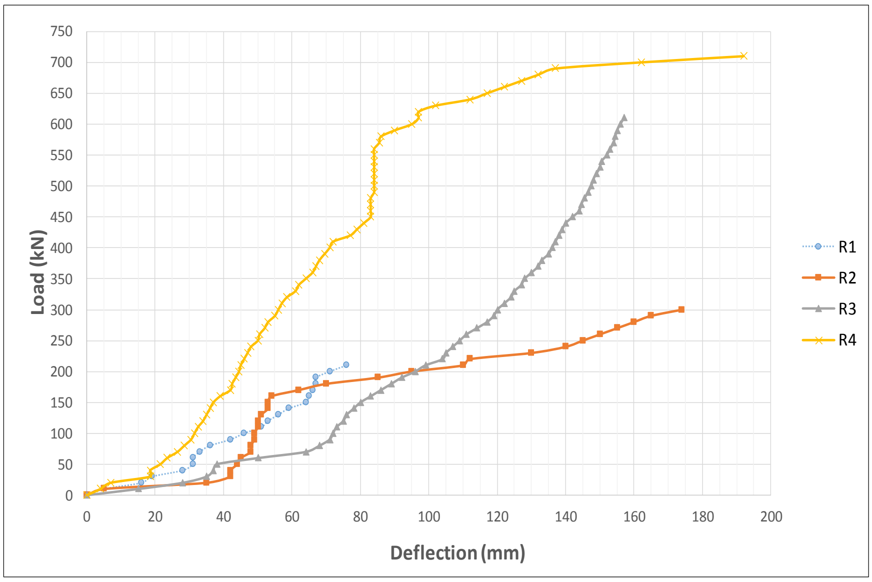


Figure 7. Load–deflection relationship of specimens without sulphate attack

The best behavior was recognized in the R4 column, which has silica fume and steel fibres together; this combination provides the column with more ductile behavior and definitely supports more of the ultimate load. The effect of silica fumes changed the effect of steel fibres; we observed this from the differences in the behavior of columns R3 and R4, and the effect of steel fibres clearly appears from behavior differences between R2 and R4, as shown in Figure 7. The abovementioned behaviors explain the benefits of using a combination of steel fibres and silica fume in a reinforced concrete column with a circular section. The increase in the absorption capacity of the column with silica fume and steel fibres is due to the increase in compressive strength. Silica fume consolidates concrete by reducing its permeability and increasing ductility; thus, the durability of concrete also improves. The effect of the mineral admixtures enhances SCC properties, especially compressive strength [12, 18, 19] and the use of straight steel fibres increases the load strength [20, 21].

4.1.2. Group 2 (R1-2%, R2-2%, R3-3% and R4-2%)

In these experiments, the columns were immersed in 2% acidic solution for 30 days and then tested. Figure 8 shows that the behavior of these specimens under these experimental conditions is highly ductile, especially for column R3 - 2%. This result is evident when comparing the behavior of these columns under 2% acid attacks and without acid (R3). This finding can be due to the sensitivity of steel fibres to acid. In addition, when we compared the other columns using the same loads, we determined that the behavior becomes flat and soft, and the acid effect is clear for ultimate load capability, as expected. The deterioration of columns depends on the type of concrete additions used in the admixtures, the improvement of the admixtures on the concrete sulphate resistance [7, 22], and, in this case, the combination of steel fibres and silica fume, which increases the compressive strength of concrete. In this study, we showed the important effect of combining silica fume with steel fibres to deal with the impermeability effect on sulphate resistance, which is reduced and improved by the combination of silica fume and steel fibres, as shown in Figure 8.

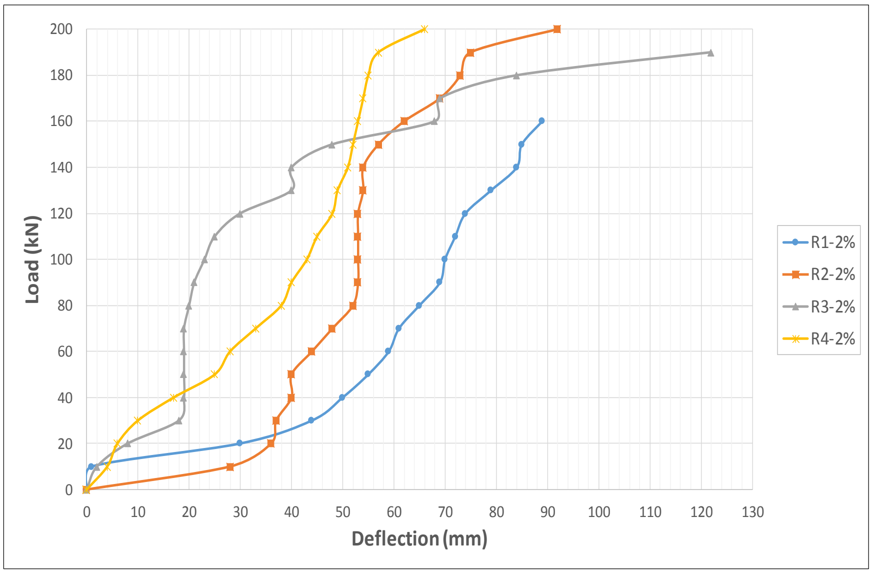


Figure 8. Load–deflection relationship of specimens attacked by 2% sulphate

4.1.3 Group 3 (R1-4%, R2-4%, R3-4% and R4-4%)

For this experiment, the specimens were immersed in 4% acidic solution for 30 days and then tested. Column R1 - 4% shows the worst behavior, where deterioration due to the acid is quite clear, as shown in Figures 15, 16 and 17. Moreover, the ultimate load curve shows more softened and large values of deflection. The specimen with steel fibres R3 - 4% still exhibits stiff behavior; however, its capability for supporting ultimate load has decreased. For the column with silica fume, only R2 - 4% shows more stiffness and slightly affects the ultimate load compared to when they were immersed with 2% acid, as shown in Figure 9.

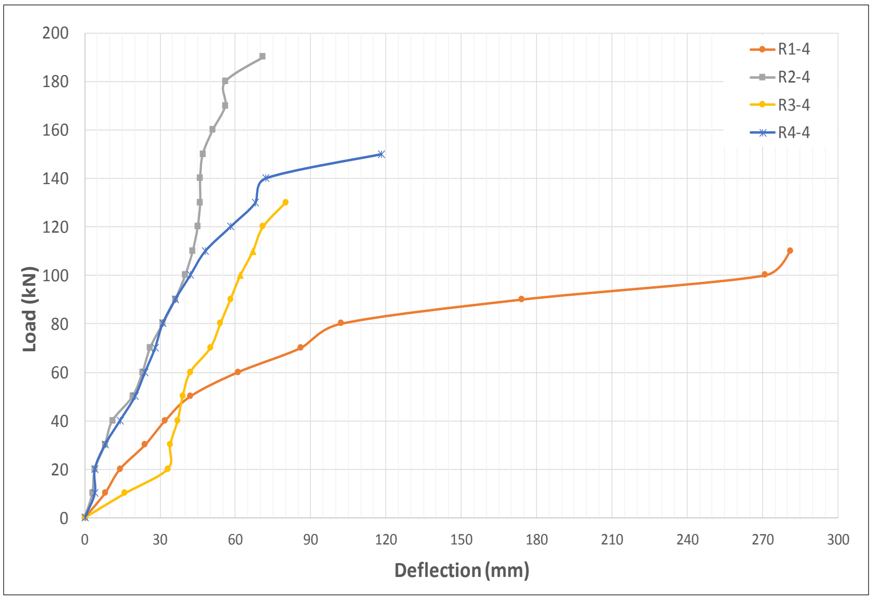


Figure 9. Load–deflection relationship of specimens attacked by 4% sulphate

The mix between steel fibres and silica fume for column R4 - 4% shows good results, but does not have the same effect as that in 2% acid attack. Other researchers have referred to the effect of using mineral admixtures on sulphate resistance with different acid concentrations [19, 23]. They supported the fact that an increase in sulphate concentration increases the deterioration of SCC properties [22] and that the mineral admixtures used reduce these deteriorations, as shown in this study.

4.1.4. Sulphate Acid Concentration Effect on Load–Deflection Relationships

By comparing the effect of acid on columns casted with the same type of concrete (admixture) and with different loads, we found that the columns casted with SCC only subjected to 2% acid solution (R1 - 2%) have the same as the control columns but with a decrease in ultimate load. Meanwhile, the columns subjected to 4% acid solution (R1 - 4%) have deteriorated in and in ultimate load. This finding proved that an increase in the concentration of sulphate acid increases the speed of acid penetration in concrete, which evidently decreases the bond between concrete and steel reinforcement [22] and weakens the load capacity of the columns, as shown in Figure 10.

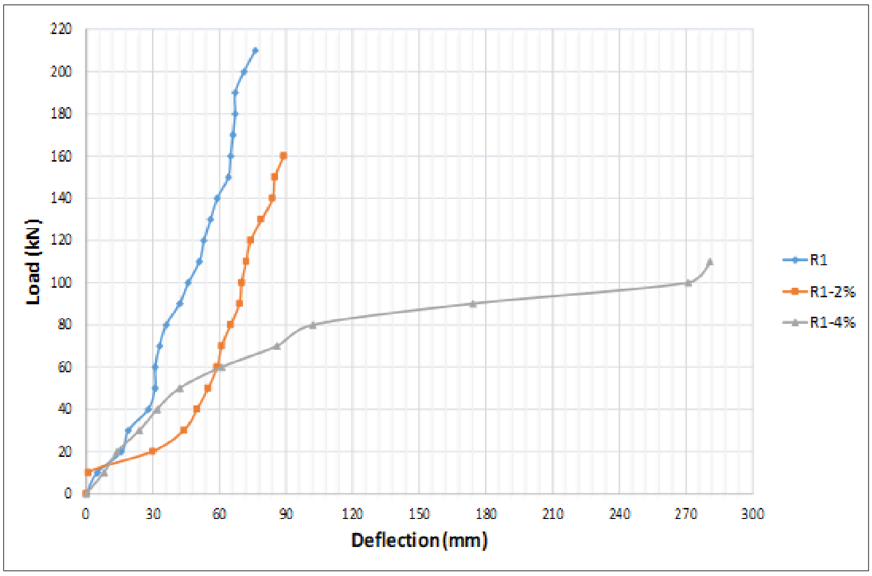


Figure 10. Load–deflection relationship of control specimens

The second group, R2 - 2% and R2 - 4%, casted with SCC and silica fume, shows almost the same when subjected to 2% acid attack and somewhat similar with 4% acid attack, with more rigid caused by the increase in acid concentration and reduction in the concrete–steel bond, which decreased the ductility of the column. However, the acid attack certainly reduces the ultimate load and the absorption capacity of the load because of the reduction in compressive strength when exposed to acid, as shown in Figure 11.

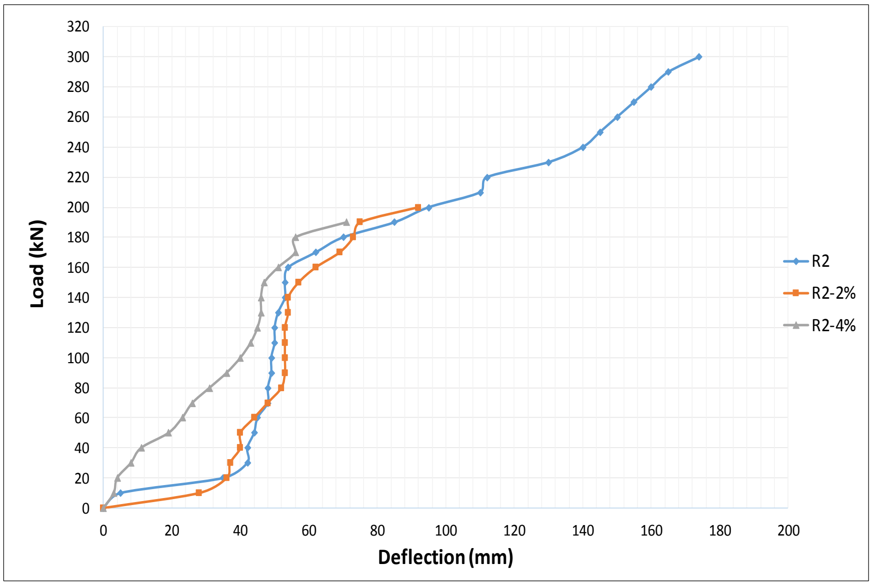


Figure 11. Load–deflection relationship of self-compacting concrete with silica specimens attacked by 2% and 4% sulphate

For the third group, R3 - 2% and R3 - 4%, which were cast with SCC and steel fibres, the effect of acid on the stiff of the control specimen is recognizable, especially at 4% acid attack, confirming the sensitivity of steel fibres against acid and the porosity of SCC when steel fibres is used, which increases acid penetration, as shown in Figure 12.

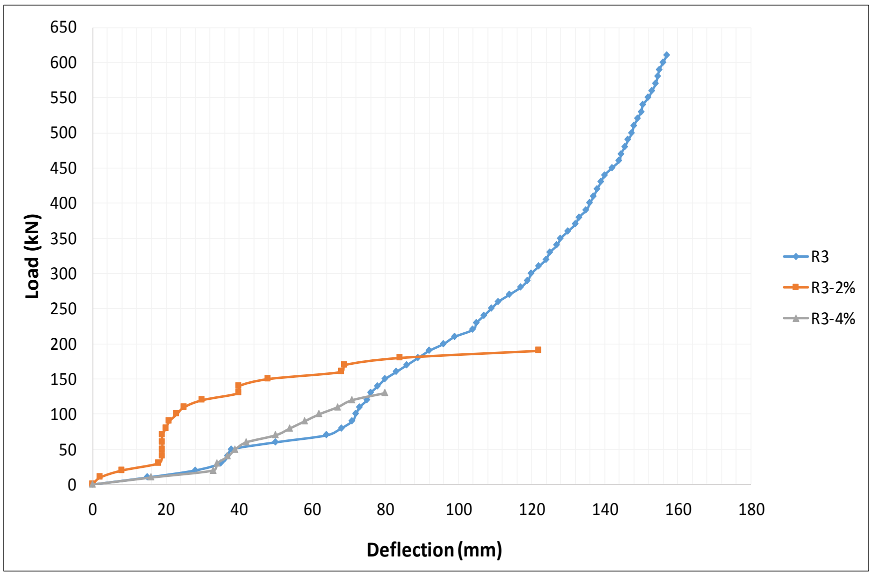


Figure 12. Load–deflection relationship of SCC with steel fibres specimens attacked by 2% and 4% sulphate

For the last group, R4 - 2% and R4 - 4%, the behavior of the columns has deteriorated and softened. The effect of combining steel fibres and silica fume reduces the porosity of concrete, protects the steel and steel fibres from acids and improves ductile behavior. However, the acid attack certainly reduces the ultimate load, as shown in Figure 13.

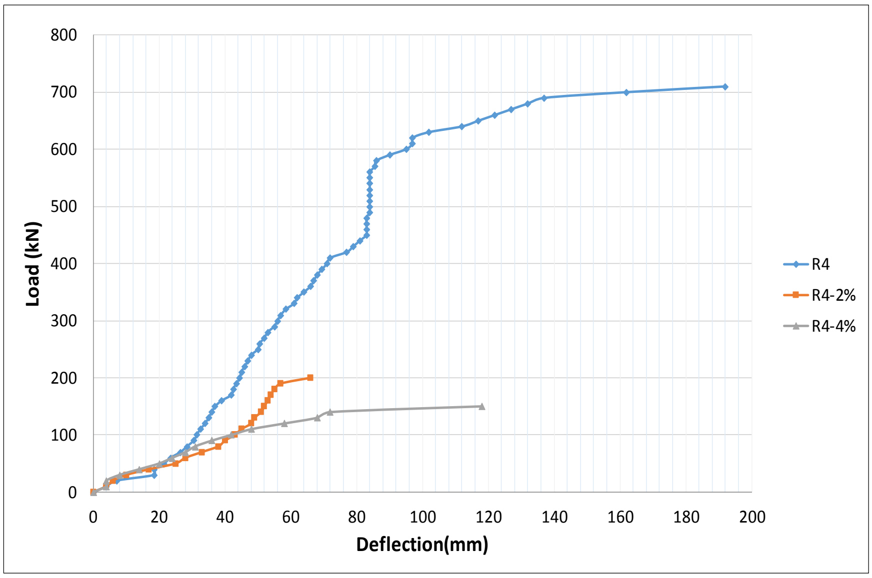


Figure 13. Load–deflection relationship of self-compacting concrete with silica and steel fibres specimens attacked by 2% and 4% sulphate

4.2. Ultimate Failure Load and Compressive Strength

4.2.1. Group 1 (R1, R2, R3 and R4)

Clearly, the compound of silica fume and steel fibres (volume fraction of 1% and 0.1 of concrete) with SCC is the best combination. This combination has increased the failure load of columns casted with only SCC by 238% and compressive strength by 112.37%, which is consistent with some researchers' recommendations [12]. Using steel fibres at 1% volume increases the failure load by 190.4% and compressive strength (cube 150 mm) by 21.35%. Meanwhile, the use of silica fume (10% of cement weight) increases the failure load by 42.85% and compressive strength (cube 150 mm) by 100%. All of the above ratios were compared with the control specimen cast from SCC only, as shown in Table 7. The effect of sulphate attack has been discussed by several researchers, and all of them agree that permeability reduction using mineral admixtures or other methods enhances sulphate resistance [19, 22, 23].

Table 5. Failure load, compressive strengths and the effect of sulphate attack

Column groups	Column	Failure load (kN)	Compressive strength for cubes (N/mm^2) (MPa)	(Increasing percentage of failure load as a ratio from the control column R1) (%) $\frac{(\text{Load of column} - \text{Load of R1})}{Load\ of\ R1} \times 100$	(Reduction percentage of failure load from the control of each group) (%) $\frac{Load\ of\ R1 - Load\ of\ column}{Load\ of\ R1} \times 100$
Control self-compacting concrete (SCC)	R1	210	41.2		-
	R1-2%	160	26.9		23.8
	R1-4%	110	25.6		47.6
SCC with silica	R2	300	82.5	42.85	-
	R2-2%	200	36.2		33.34
	R2-4%	190	28.9		36.67
SCC with steel fibres	R3	610	50	190.4	-
	R3-2%	190	33.5		68.85
	R3-4%	130	28.6		78.68
SCC with silica and steel fibres	R4	710	87.5	238	-
	R4-2%	200	39.4		71.83
	R4-4%	150	35		78.87

4.2.2. Group 2 (R1-2%, R2-2%, R3-3% and R4-2%)

When the columns were subjected to 2% sulphate attack, the use of silica fume (R2 - 2%) and steel fibres (R3 - 2%) increases the column's ultimate load by 25% and 18.75% compared with the R1-2% (SCC only), respectively. Using the combination of steel fibres and silica fume (R4 - 2%), the column's ultimate load increased by 25% relative to the control columns without any addition (R1 - 2%). The effects of exposure to 2% sulphate acid on the ultimate load of the columns are as follows:

- Columns without any addition and subjected to 2% acid attack (R1 - 2%) had a reduction of 23.8% in ultimate load relative to the control columns (R1), which were not attacked by sulphate.
- When using the silica fume (R2 - 2%), the reduction was only 33.34% from the control column (R2); this result showed the benefit of using silica fume, which reduces the porosity of concrete and, as a consequence, minimises the effect of the acid.
- When using steel fibres, the reduction in failure load due to the acid attack (R3 - 2%) was 68.82%; this reduction can be attributed to the increase in the porosity of concrete when using steel fibres and the sensitivity of steel to the acid, which causes steel to rust.
- Finally, the one with steel fibres and silica fume was the worst scenario; the reduction was 71.83% from the control column R4; this significant reduction was caused by using steel fibres, which, despite the benefit of using silica fume, increased porosity and decreased failure load.

4.2.3. Group 3 (R1-4%, R2-4%, R3-4% and R4-4%)

Under a 4% sulphate attack, the silica fume (R2 - 4%) and steel fibres (R3 - 4%) increased the column's ultimate load by 72.72% and 18.18% compared with (R1 - 4%), respectively. When the steel fibres and silica fume were combined (R4 - 4%), the column's ultimate load increased by 36.36% compared with the control column without any addition (R1 - 4%). For the columns casted with silica fume and attacked with 4% acid, the reduction in the failure load was 36.67% relative to the control column R2. This result showed the benefit of using silica fume, which reduced porosity.

In the case of control columns without any addition (R1 - 4%), the reduction was 47.6% from the control column R1. When steel fibres were used, the reduction was 78.68% from the control column R3. For the last case, when using the combination of steel fibres and silica fume (R4 - 4%), the reduction was 78.87% from the control column R4, which represented the worst case, as shown in Figure 14.

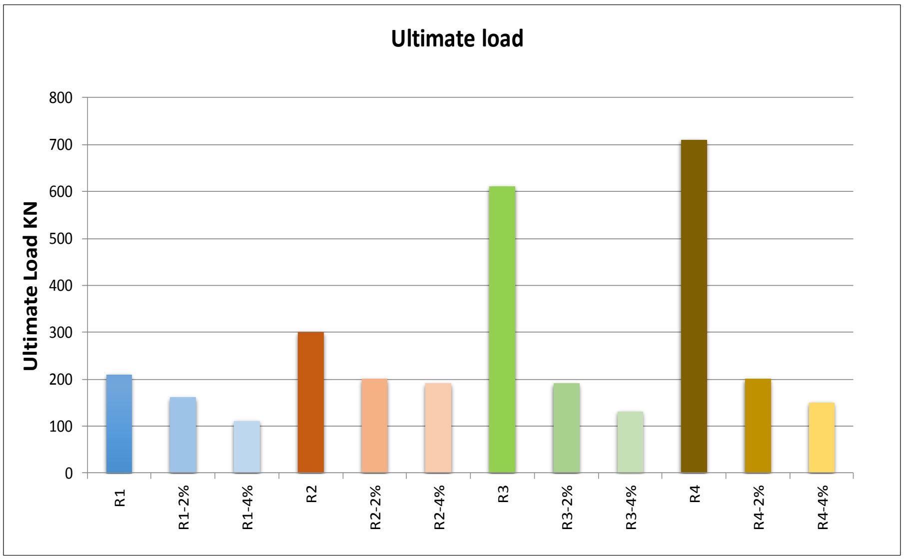


Figure 14. Ultimate load for all specimens with different cases of sulphate attack

4.3. Failure Mode and Crack Analysis

All specimens had a crushed concrete failure from the top to the bottom ends with major diagonal cracks, except for the steel fibres group, after sulphate attack. The crushing started from the bottom towards the top ends. The same failure mode was shown by Liu et al. [24]; all mechanisms started at the top and bottom ends with thin cracks that increased in width and length, as shown in Figures 15 to 17. During the experimental test, crack-causing velocity in concrete increased with load [24–26]. From the shape of the failure, the use of steel fibres clearly made the column weak when exposed to sulphate attack because of the steel reinforcement corrosion caused by acid [22].

Figure 15. Group 1

Figure 16. Group 2 during the test

Figure 17. Group 3 during the test

The cracks started at the circumference of the top and bottom bases of the columns and then progressed towards the middle of the column height in a straight and diagonal manner. As the load increased, the crack width widened, and the cracks started in a horizontal manner around the column's surfaces. Furthermore, spalling occurred in all specimens. However, less spalling occurred in specimens that contained steel fibres than in the other specimens. The crash at the column ends appeared in all specimens with different shapes. The worst crush occurred in specimens exposed to 4% sulphate acid.

4.4. Colour of Columns and Corrosion Zones

After 30 days of sulphate attack, the color of columns at the zone of exposure to acid became white, and the zone was blown, as shown in other studies [23], except for columns containing steel fibres, which became white and produced a rusty color, as the acid caused rust in the steel fibres. Columns without steel fibres had minimal corrosion at the exposure zone, whereas columns with steel fibres demonstrated clear corrosion.

5. Conclusions

From the study results, we can enhance the ultimate load of the SCC-reinforced columns by using steel fibres, silica fume, and their combination. This enhancement improves the properties of concrete. The speed of appearance and the width of the cracks were reduced when using steel fibres and silica fume. The behavior of the load–deflection curve was ductile. More importantly, when using steel fibres and silica fume, the ultimate load and ductile behavior improved.

When partially immersed in sulphate acid, sulphate attack resistance increased when using silica fume (10% of cement weight), and when using steel fibres, minimal differences were observed. Furthermore, when using their combination. In the case of a 2% acid concentration. When the columns were exposed to 4% acid, the use of silica fume enhanced the sulphate resistance more than using steel fibres, which is because permeability is reduced by silica fume; however, using steel fibres still improves sulphate resistance. To improve the permeability caused by using steel fibres, we combined them, and this combination increased sulphate resistance more than using steel fibres.

In addition to all the previously mentioned behaviors of the columns, using silica fume improved ductility when exposed to a partial sulphate attack. The stiffer property of the steel fibres near the failure load also softened due to the sulphate attack. The combination of steel fibres and silica fume improved the behavior of the ductile load–deflection relationship and failure progress.

In this study, we discussed the effects of partially immersing in sulphate acid the different types of reinforced SCC columns, variations of using silica fume and steel fibres and their combinations on sulphate resistance. More studies are necessary, especially regarding the strain in concrete and steel. Furthermore, other mineral admixtures, such as fly ash; other types of concrete, such as normal and high-strength concrete; and several other types of materials can be used.

6. Declarations

6.1. Author Contributions

Conceptualization, N.M. and S.S.; methodology, N.M., L.S.; formal analysis, N.M.; investigation, N.M.; resources, N.M., L.S. and S.S.; data curation, N.M.; writing—original draft preparation, N.M.; writing—review and editing, N.M.; visualization, N.M.; supervision, S.S.; project administration, N.M., L.S. and S.S.; funding acquisition, N.M., L.S. and S.S. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

6.3. Funding

The authors received no financial support for the research, authorship and/or publication of this article.

6.4. Acknowledgements

The authors would like to thank Mustansiriyah University (*www.uomustansiriyah.edu.iq*) in Baghdad, Iraq, for its support in the present work.

6.5. Conflicts of Interest

The authors declare no conflict of interest.

7. References

[1] Türkel, S., Felekoǧlu, B., & Dulluç, S. (2007). Influence of various acids on the physico-mechanical properties of pozzolanic cement mortars. Sadhana, 32(6), 683–691. doi:10.1007/s12046-007-0048-0.

[2] Bassuoni, M. T., Nehdi, M., & Amin, M. (2007). Self-compacting concrete: Using limestone to resist sulfuric acid. Proceedings of Institution of Civil Engineers: Construction Materials, 160(3), 113–123. doi:10.1680/coma.2007.160.3.113.

[3] Hewlett, P. C., & Liska, M. (2019). Lea's chemistry of cement and concrete. Butterworth-Heinemann, Massachusetts, United States. doi:10.1016/B978-0-7506-6256-7.X5007-3.

[4] Basheer, L., Kropp, J., & Cleland, D. J. (2001). Assessment of the durability of concrete from its permeation properties: A review. Construction and Building Materials, 15(2–3), 93–103. doi:10.1016/S0950-0618(00)00058-1.

[5] Wang, J. G. (1994). Sulfate attack on hardened cement paste. Cement and Concrete Research, 24(4), 735–742. doi:10.1016/0008-8846(94)90199-6.

[6] Makhloufi, Z., Kadri, E. H., Bouhicha, M., & Benaissa, A. (2012). Resistance of limestone mortars with quaternary binders to sulfuric acid solution. Construction and Building Materials, 26(1), 497–504. doi:10.1016/j.conbuildmat.2011.06.050.

[7] Khitab, A., Arshad, M. T., Awan, F. M., & Khan, I. (2013). Development of an acid resistant concrete: a review. International Journal of Sustainable Construction Engineering and Technology, 4(2), 33-38.

[8] Raki, L., Beaudoin, J., Alizadeh, R., Makar, J., & Sato, T. (2010). Cement and Concrete Nanoscience and Nanotechnology. Materials, 3(2), 918–942. doi:10.3390/ma3020918.

[9] Rasheed, L., Salih, S., & Hanash, Z. (2018). Behavior of normal reinforced concrete columns exposed to different soils. MATEC Web of Conferences, 162, 04018. doi:10.1051/matecconf/201816204018.

[10] Nochaiya, T., Wongkeo, W., & Chaipanich, A. (2010). Utilization of fly ash with silica fume and properties of Portland cement-fly ash-silica fume concrete. Fuel, 89(3), 768–774. doi:10.1016/j.fuel.2009.10.003.

[11] Caballero, C. E., Sanchez, E., Cano, U., Gonzalez, J. G., & Castaño, V. (2000). On the effect of fly ash on the corrosion properties of reinforced mortars. Corrosion Reviews, 18(2–3), 105–112. doi:10.1515/CORRREV.2000.18.2-3.105.

[12] Mohamed, A. F., Shafiq, N., Nuruddin, M. F., & Elheber, A. (2013). Effect of silica fume on the properties of steel-fibres reinforced self-compacting concrete. International Journal of Civil and Environmental Engineering, 7(10), 754-758. doi:10.5281/zenodo.1088572.

[13] Huynh-Xuan, T., Do-Dai, T., Ngo-Thanh, T., Pham, T. M., & Nguyen-Minh, L. (2021). Effect of Sulfate Attack on Reinforced Concrete Columns Confined with CFRP Sheets under Axial Compression. Journal of Composites for Construction, 25(6). doi:10.1061/(asce)cc.1943-5614.0001151.

[14] ANWAR, M., & Makhlouf, A. (2021). Performance of Fly Ash Concrete against Sulfate Attack. Journal of Engineering Sciences, 49(No 2), 178–197. doi:10.21608/jesaun.2021.53250.1024.

[15] Selvan, S. (2021). Effect of Cement Composition in Concrete on Resisting External Sulfate Attack. Journal of Xi'an University of Architecture & Technology, XIII(4), 470–480.

[16] Bektimirova, U., Sharafutdinov, E., Shon, C., Zhang, D., & Kim, J. (2020). Statistical Analysis of Sulfate Attack Resistance of Reactive Powder Concrete. XV International Conference on Durability of Building Materials and Components. EBook of Proceedings. doi:10.23967/dbmc.2020.129.

[17] Rasheed, L. S., Salih, S. A., & Hanash, Z. F. (2020). The of Polymer RC Columns Exposed to aggressive Soils. IOP Conference Series: Materials Science and Engineering, 888(1), 12009. doi:10.1088/1757-899X/888/1/012009.

[18] Uysal, M., & Yilmaz, K. (2011). Effect of mineral admixtures on properties of self-compacting concrete. Cement and Concrete Composites, 33(7), 771–776. doi:10.1016/j.cemconcomp.2011.04.005.

[19] Phani, S.S., Seshadri, S.T., Rao, S., Sravana, & Sarik, P. (2013). Studies on Effect of Mineral Admixtures on Durability Properties of High Strength Self Compacting Concrete. International Journal of Research in Engineering and Technology, 2(09), 98–104. doi:10.15623/ijret.2013.0209016.

[20] Mhuder, W. J., & Chassib, S. M. (2020). Experimental study of strengthening of RC columns with steel fibres concrete. Materials Science Forum, 1002, 551–564. doi:10.4028/www.scientific.net/MSF.1002.551.

[21] Qasim, O. A. (2018). of Different Self-Compacted Concrete Mixes on Short Reinforced Concrete Columns. International Journal of Applied Engineering Research, 13(2), 1014-1034.

[22] Mosleh Salman, M., & Abdul Ghani Zghair, L. (2018). of Self Compacting Concrete Subjected to Sulphuric Acid. Journal of Engineering and Sustainable Development, 2018(05), 01–09. doi:10.31272/jeasd.2018.5.1.

[23] Dakshina Murthy N.R., Raaseshu D., Seshagiri Rao M.V. (2007). Studies on fly ash concrete under sulphate attack in ordinary, standard and higher grades at earlier ages. Asian Journal of Civil Engineering and Housing, 8(2): 203–214.

[24] Liu, T., Zou, D., Teng, J., & Yan, G. (2012). The influence of sulfate attack on the dynamic properties of concrete column. Construction and Building Materials, 28(1), 201–207. doi:10.1016/j.conbuildmat.2011.08.036.

[25] Neville, A. (2004). The confused world of sulfate attack on concrete. Cement and Concrete Research, 34(8), 1275–1296. doi:10.1016/j.cemconres.2004.04.004.

[26] Girardi, F., Vaona, W., & Di Maggio, R. (2010). Resistance of different types of concretes to cyclic sulfuric acid and sodium sulfate attack. Cement and Concrete Composites, 32(8), 595–602. doi:10.1016/j.cemconcomp.2010.07.002.