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Vancouver, Canada

May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

THE EFFECT OF CEMENT TYPE ON CONCRETE RESISTANCE TO SULPHATES

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Abstract: Concrete resistance to aggressive sulfates is of paramount importance to concrete performance in many parts of the world. This study aims at evaluating concrete performance to sulfates of various concentration. Concrete Mixes were prepared with Portland Slag Cement, Portland Sulfate Resisting Cement, Portland Limestone Cement and Ordinary Portland Cement and were subjected to an experimental study. Tests included fresh concrete properties as well as hardened concrete properties. Another set of tests were allocated to chemical resistance to sulfates for several weeks. The outcome of this study reveals that exposure characteristics are highly affected by the selection of the cement type. Recommendations are made for applicators to better select the adequate cement type when serving in sulfate environment. Ultimately, this study can be a step towards proper selection of cement type in light of the nature of sulfate concentrations encountered.

1.0 Introduction

The durability of concrete has always been affected by sulfate attacks. Sulfate attack is a chemical process that results in the breakdown of cement paste when attacked by sulfate ions, it can either be internal or external. Chemicals that cause sulfate attack are usually found in water since water is a solvent of chemicals such as calcium, magnesium, potassium and sodium which are responsible for sulfate attack. Sulfate attack may manifest itself in different forms depending on the chemical state of the sulfate and the atmospheric conditions under which the concrete is exposed to.

External sulfate attack is common and predominant dissolved sulfate in water finds its way inside concrete. For external sulfate attack to occur, there should be high permeability of concrete, sulfate rich environment and presence of water. The reaction is more common in polished areas of the concrete. The concrete looks normal ahead the reaction region but in the rear of the reaction face the composition of the concrete will already be changed. The degree of damage determines the type of changes on the concrete. The common changes are; widespread cracking, expansion, no adhesion between cement stick and aggregate and adjustment of paste composition resulting to formation of gypsum composition. These changes causes weakening of the structure. More server damages are experienced when the concrete is subjected magnesium sulfate solutions. This is because during the chemical reaction magnesium is the replacement of calcium in the solid phases.

Therefore, the objective of this work is to test and evaluate the impact of different exposure of sulphate attack on concrete with different Portland cement. A standard concrete mixture was prepared for the four types of Portland cement; Ordinary Portland cement (OPC), Portland Slag cement (PSC), Portland Limestone cement (PLC) and Sulphate Resisting cement (SRC). The different Portland cements were subjected to concentrations of 10%, 40% and a Saturated solution and tested in the form of cubes and beams to simulate and analyze the resistance of concrete with different Portland cements to sulphate attack.

Experimental Program

1.1 Material Properties

Cement: The four types of Portland cements that were tested include:

- Type I Ordinary Portland Cement
- Type IL Portland-Limestone Cement
- Type IS Portland-Slag Cement
- Type V Portland Cement

Fine Aggregates: Natural sand with a SSD specific gravity of 2.55 was used.

Coarse Aggregates: Well-graded coarse aggregate with a SSD specific gravity of 2.61 was used.

Water: Ordinary tap water was used in the experimental work, which includes the concrete mix and the curing of concrete.

Admixtures: A plasticizing retarder, Type B & D, in accordance with ASTM C-494, was used. It had a specific gravity of 1.15

Sulphate: Fully water soluble $MgSO_4$ was used in the testing. It contains 16% MgO and 32% SO_3.

1.2 Concrete Mix Design

The conventional concrete mixture that was used in this investigation is shown in Table 1. An incidental air content of 2% was assumed and a water-to-cement ratio of 0.45 was used. A plasticizing retarder was added to the mixture with a quantity of 2% of the weight of cement used. This concrete mixture was done for all specimens in compliance with the testing procedure of the ASTM.

Table 1 - Mix Design

Item	Quantities (kg/m^3)
Cement	400
Water	180
Fine aggregates	600
Coarse aggregates	1200

1.3 Tests

Fresh concrete: Tests were carried out on fresh concrete in compliance with the ASTM. These tests include: Slump, air content, temperature and unit weight tests

Hardened concrete: A breakdown of the hardened concrete tests is shown in Table 2. The tests were categorized into two main types to characterize the purpose of these tests. Compressive and flexural strength tests were done to assess the mechanical properties of the hardened concrete. While sulphate resistance tests included compressive and flexural strength after exposure of different concentrations of $MgSO_4$, mass change and chemical tests that include Scanning Electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR).

Table 2 - Hardened Tests

		Test	Specimen	Age of Testing
Standard Tests		Compressive strength	150x150x150 mm cubes	7-day, 28-day, 56-day
		Flexural strength	750x150x150 mm beams	28-day
Sulphate resistance	Destructive	Compressive strength	50x50x50 mm cubes	7-day, 14-day, 21 day, 28-day, 42-day, 56-day
		Flexural strength	210x70x70 mm beams	28-day and 56-day
	Non-Destructive	Change in Mass	50x50x50 mm cubes	7-day, 14-day, 21 day, 28-day, 42-day, 56-day
			210x70x70 mm beams	
		SEM	N/A	56-day

1.3.1 Standard Tests

Compressive Strength: This test was done in accordance with the British standards for testing [BS 1881]. It was done on 150x150x150mm cubes. For each of the 4 types of cement, 3 cubes samples were taken on each age of testing.

Flexural Strength: This test was done in compliance with ASTM C78. Beams of 750x150x150mm were tested. For each of the 4 types of cement 2 beams samples were tested on the specified date as shown in Table 2.

1.3.2 Sulphate Resistance Tests

Compressive Strength: 50x50x50mm concrete cubes exposed to $MgSO_4$ were tested for compressive strength on the days specified in Table 2 above.

Flexural Strength: In accordance with ASTM C78, Beams of 210x70x70mm were tested to find the flexural strength after exposure to sulphates.

Mass Change: 50x50x50mm cubes and Beams of 210x70x70mm were weighed before and after exposure to calculate the change in mass.

Chemical Tests: SEM was performed to analyze the composition of the concrete samples comparing the different concentrations of sulphate exposure. The scanning electron microscope uses a beam of high-energy electrons emitted on a solid specimen, which then helps to display the external texture, chemical composition and crystalline structure and orientation of the materials making up the specimen, magnifications can be done within a range of 20X to 30,000X. It is also capable of determining the chemical composition. The purpose of using SEM in our research is finding out how the voids change with 10%, 40% and saturated concentration of sulfate. All of the results have the same magnification of 150X.

2.0 Test Results and Discussion

2.1 Fresh concrete results

Table 3 - Fresh Concrete Results

Cement types	Tests Results				
	Slump (mm)	Air Content (%)	Room Temperature (ºC)	Concrete Temperature (ºC)	Unit Weight
Limestone	33	1.8	23.4	24.6	2261.43
Sulphate Resistant	80	1.7	24.4	25.7	2367.14
Slag	85	1.7	23.8	26.2	2270.00
OPC	24	1.55	24.1	25.2	2354.29

The results show expected results with the slump results showing that SRC and Slag cement have the highest workability even though the concrete mix design was similar in all the cement types. An incidental air content was assumed to be 2%, and was the same in all the cement types. Temperature differences proved inconsistent with actual results as OPC claimed the lowest result but showcased the highest early strength, however, Sulphate Resistant Cement and Slag Cement were compatible with the high difference as they gained high early strength. Limestone had low early strength also compatible with the results. Unit weight for all types was according to standard, which served as assurance towards the mix design and the standard quality of work.

2.2 Hardened concrete results

2.2.1 Standard Tests

Compressive Strength: The results of the compressive test results are presented in Figure 1 for the different portland cement types at 7-day, 28-day, 56-day. The compressive strength test was conducted to provide assurance of the quality of cement used by examining their standard compressive strength. The samples are 150x150x150mm in size. The results were also used for comparison with the results of the smaller cubes that were used as a control mix that was not subjected to sulphate shown in Figure 2.

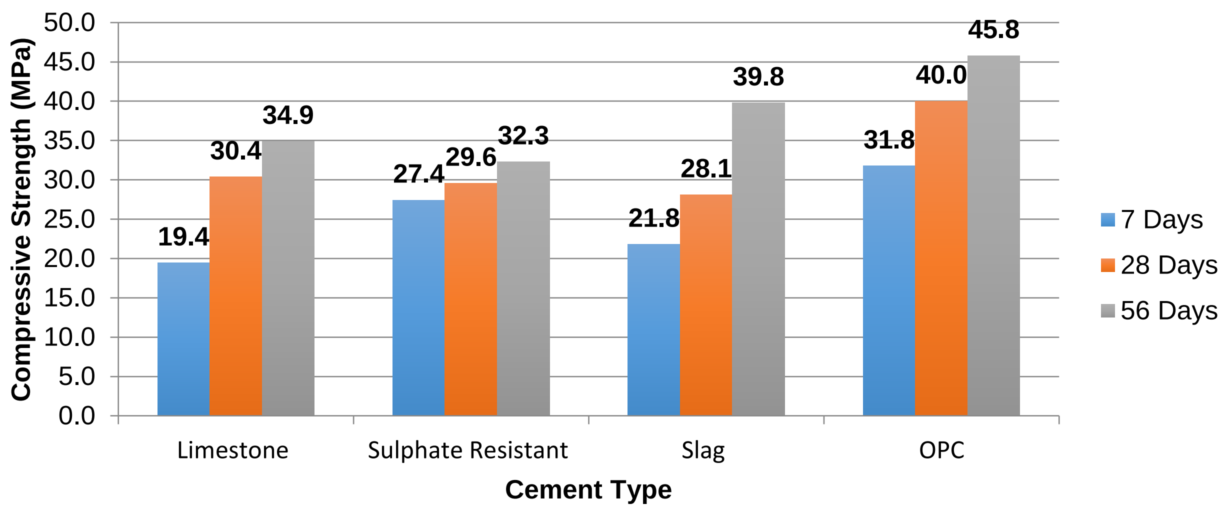


Figure 1: Compressive Strength Results

Compressive strength test results were adequate for all types of cement as they reached the requirement of 30 MPa after 56 days. These results entailed that the four types of cement are in fact of high quality and can be used in structural applications. The results evidently show that OPC has the highest strength with 45.78 MPa, followed by Slag and Limestone cements at 39.78 and 34.9 MPa respectively, with sulfate resisting cement showcasing the lowest strength of all the types at 32.29 MPa. The relatively low value of SRC was unexpected as limestone cement was expected to be the least compressively sound. This could be attributed to the fact that Limestone cement had a 25% of limestone integrated and therefore is of relatively high strength. Research conducted shows that an extra percentage of limestone mixed with OPC would in fact lead to higher strength. However, the SRC result indicates that further testing needs to be conducted on this type. According to the research done, SRC has a low 28-day compressive strength due to its chemical nature and that it gains most of its strength after 28 days as is also shown in Figure 1.

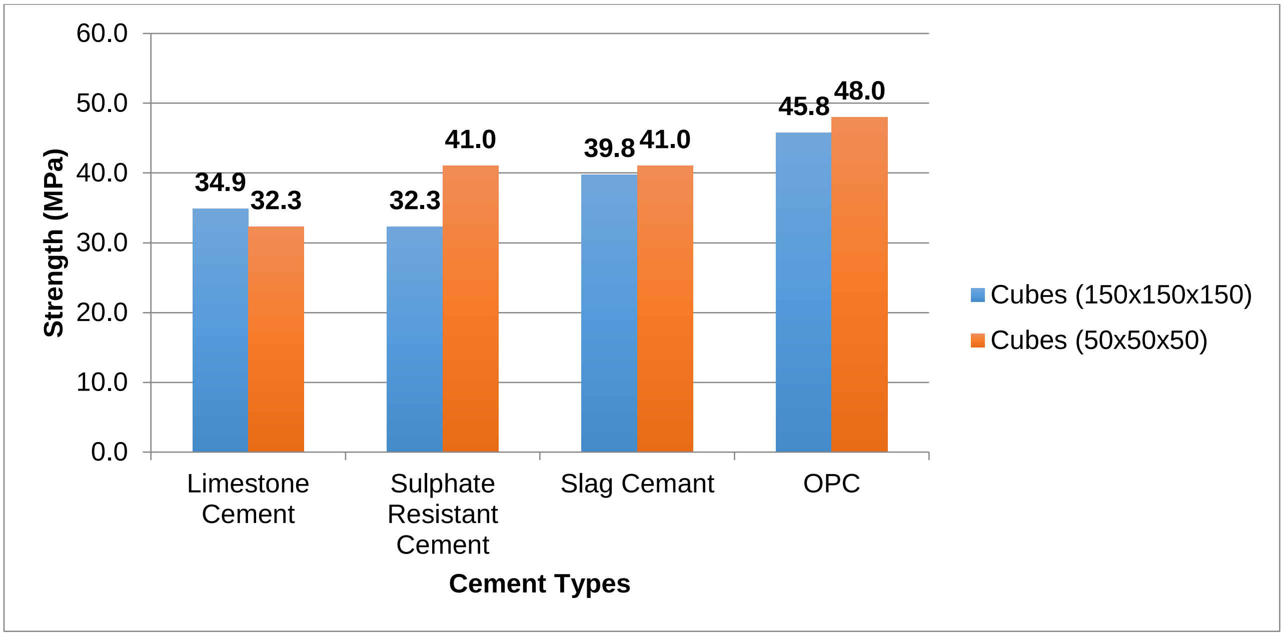


Figure 2: control mix (50X50X50mm) vs. cubes (150X150X150mm)

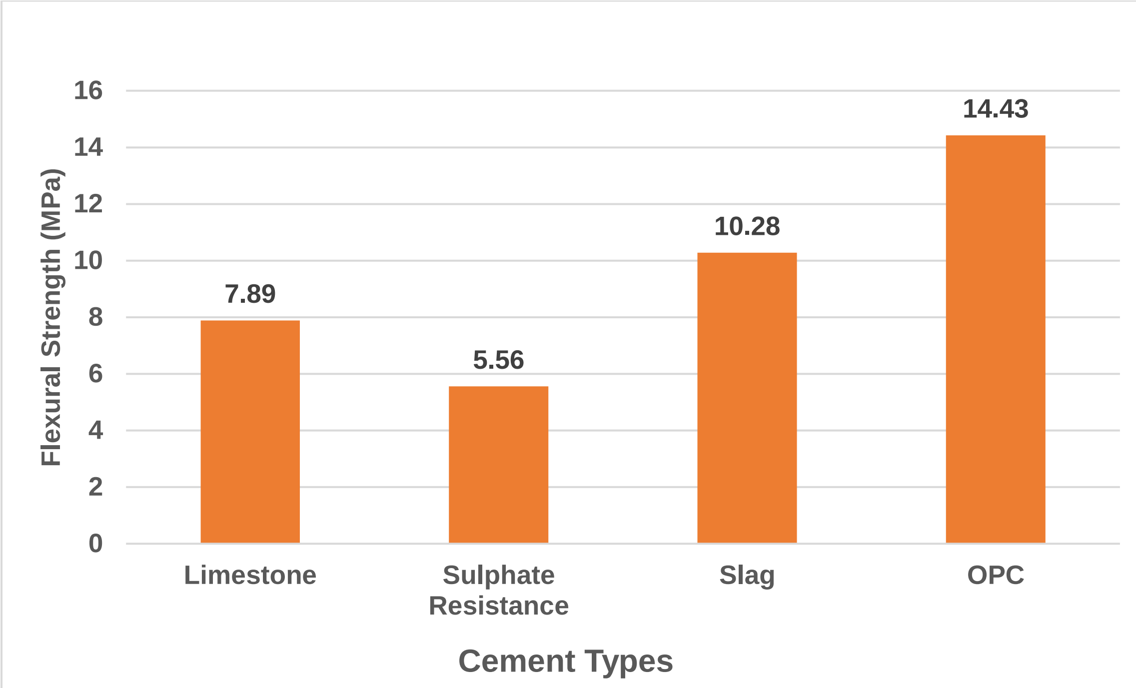
The control mix test results after approximately 45 days showed a resemblance to the "non-exposed" sample results after 56 days, this demonstrates the relative accuracy of the methodology used to conduct the comparisons and compressive tests, as the results shown indicate a maximum of 20% variability regarding the difference size of the samples and their respective test results. Moreover, the results demonstrate the size factor that in fact, the smaller cubes have higher compressive strength compared to the larger cubes.

Flexural Strength: The results of the flexural strength are presented in Figure 3 for the different portland cement types at 28 days. The samples are 750x150x150mm in size.

Figure 3 - Flexural Strength Results

As shown, OPC have the highest flexural strength with SRC performing below expectations as per literature, this could be attributed to slow strength gain or poor mixing, these results are consistent with the compressive strength samples.

2.2.2 Sulphate Resistance Tests



Compressive Strength: The results of the compressive strength of the exposed concrete with different portland cements are presented in Figure 4. Table 4 below, also illustrates the compressive strength of the cubes that were subjected to the different concentrations of sulphate and the control mix that were not exposed.

Table 3 - Maximum Exposure Compressive Strength (MPa)

Types	Control Mix	10%	40%	100%
PLC	32.3	25.5	30.6	15.0
PSC	36.6	32.7	24.2	22.0
SRC	41.0	27.2	22.2	17.9
OPC	48.0	28.8	31.4	31.2

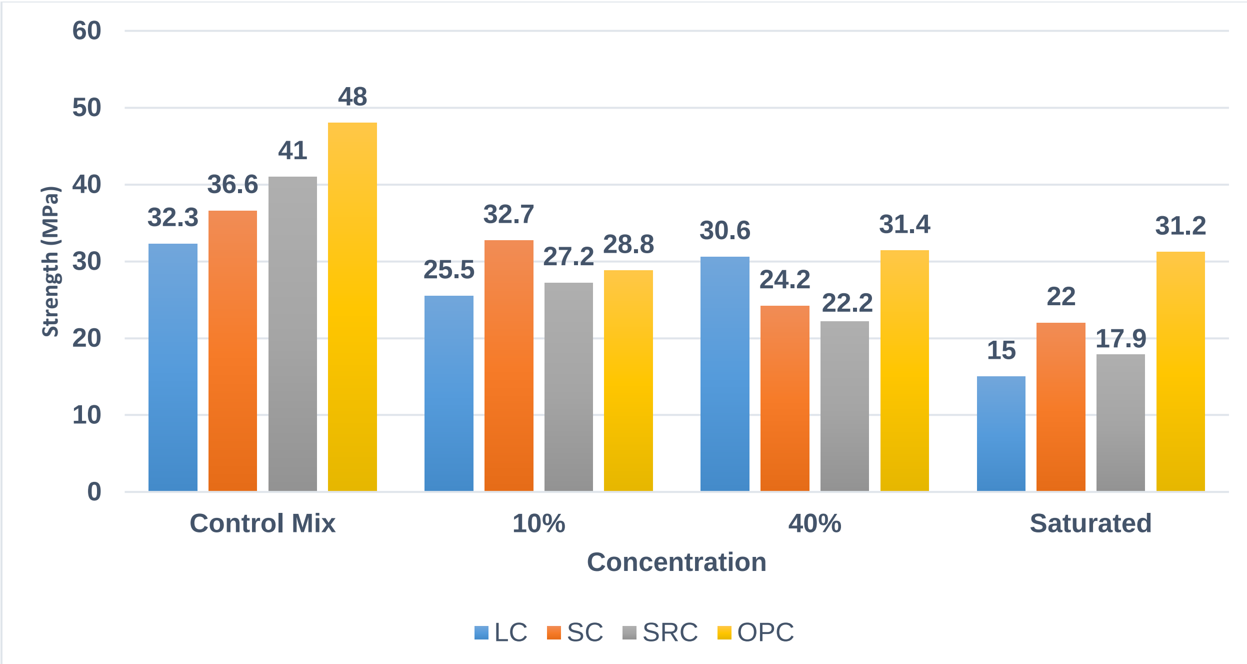


Figure 4 - Compressive Strength for exposed cubes

The compressive strength results in Figure 4, show that most of the deterioration takes place for 10% concentration and that is the most commonly existing concentration of sulphate. Also, the increase of sulphate dosage does not have much impact on strength deterioration. The results illustrate that OPC seems to be the one that retains most of its strength upon exposure to various sulphate concentrations. However, according to literature this trend might not persist or be the same post 90. Moreover, Portland Limestone cement seems to have deteriorated the most upon exposure to sulphates.

Flexural Strength: The results of the flexural strength of the exposed beams are presented in Figure 5. They were tested at 28-day and 56-day. The samples are 210x70x70mm in size.

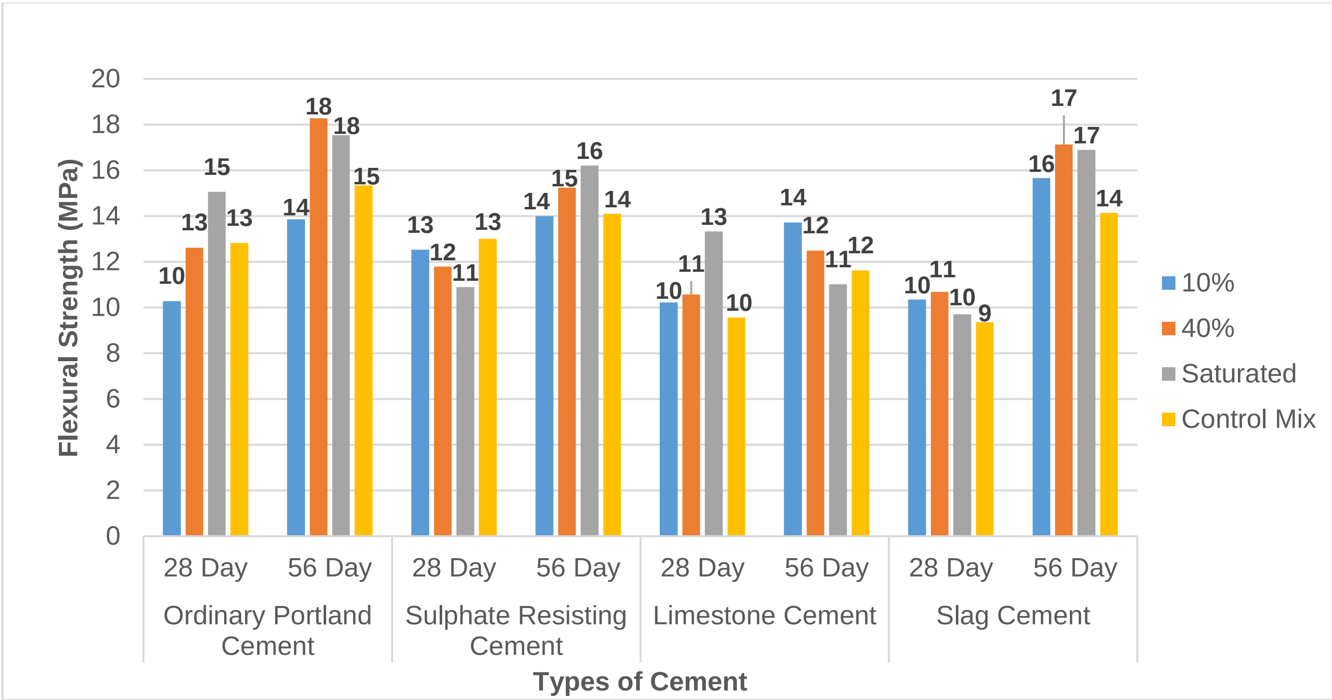


Figure 5 - Flexural Strength of Beams subjected to sulphates

The results show a trend of Strength gain after 56 days compared to the 28 day results, this could be attributed to the fact that salts fill the voids in the beams and result in higher resistance. There is another trend where OPC shows the highest % increase in strength after 56 days compared to the compressive strength results.

SEM Tests: This chemical tests was conducted to show the % of voids and a pattern of cracks caused by the exposure of sulphate. This test was done at 56-day.

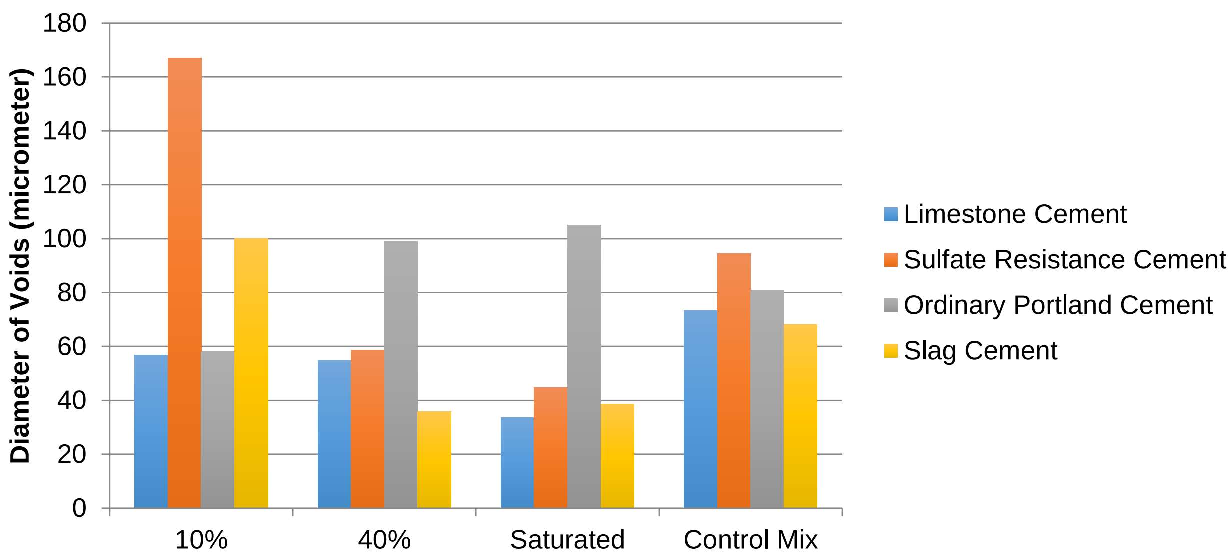


Figure 6- SEM Result

The SEM tests results shows how the diameter of voids in the concrete changes with 10%, 40% and saturated concentrated of sulfate. According to the results, the type of cement that shows increase in diameter is Ordinary Portland cement, moreover the types of cement that show decrease in diameter are slag cement, sulfate resistance cement and limestone cement.

Mass Change: Each type of cement was weighed initially after they were poured (dry weight), a comparison was done between the initial weight and weight after exposure, percentage increase or decrease was calculated; the specimens that were chosen were the small cubes (50 X 50 X 50mm). For each concentration the cubes were weighed at different times; at first they were weighed after 30 days of exposure, then after 37 days and finally after 50 days, this allowed us to know the correlation between time of exposure and change in mass.

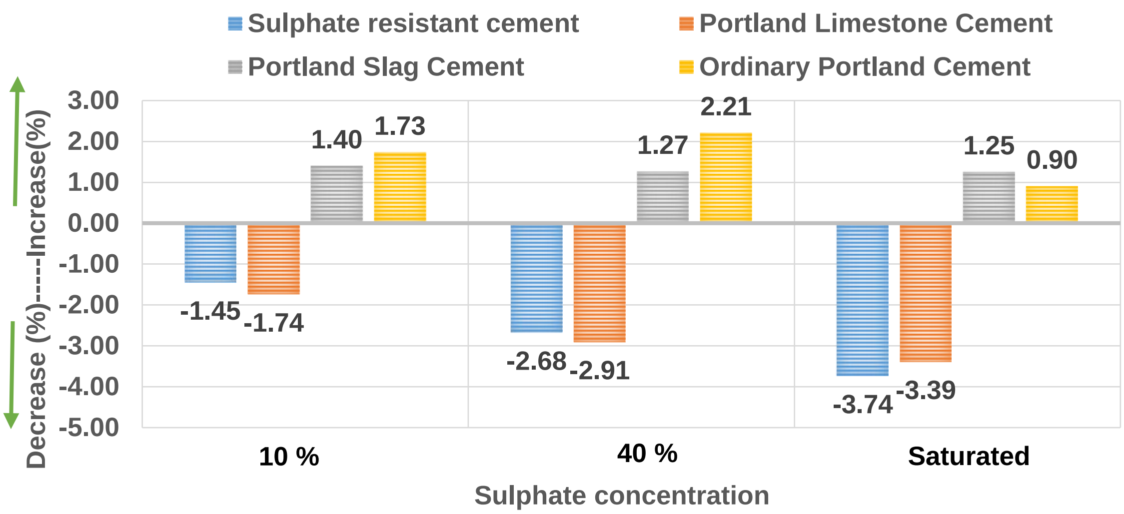


Figure 7- Mass Change Results

The two types of cement that show an increase in mass are Portland Slag Cement and Ordinary Portland Cement, on the other hand the two types of cement that show a decrease in mass are Sulphate Resistant Cement and Portland Limestone Cement. The reason behind this is that every cement type has a different reaction rate; according to scholarly sources the reaction between sulphates and concrete give out a product called ettringite which is a type of gel, which causes extensive cracking and decreases the total weight of the concrete since it is less dense than the concrete itself. This reaction seemed to have happened to the two types of cement that lost their mass through sulphate exposure (Sulphate Resistant Cement and Portland Limestone Cement), on the contrary this reaction did not happen to the other two types of cement during the course of the 56 days of exposure, the reason is that sulphate crystals formed inside the concrete without reacting to give out ettringite, so this increased the mass.

3 Conclusions

The best type of cement would have to depend on the type of concrete, and the type of sulphates causing the attack. To reaffirm that the concluding remarks are only limited to the duration of the tests that were conducted. However, it is clear from the work:

1. Most of the deterioration takes place for 10% concentration and the increase of sulphate dosage does not have much impact on strength deterioration.
2. Of all the specimens tested, ordinary Portland cement seems to be the one that retains most of its strength upon exposure to various sulphate concentrations.
3. Local slag and limestone cement did not exhibit high improvement on sulphate cement resistance.

4. Limestone and slag cement used seems to be more adequate for 10% sulphate concentration.
5. Elimination of the limestone cement in structural applications

4 Recommendations

Since the study of the impact of the different exposure of sulphate attacks on concrete with different cement types is extensive. The following recommendations can be indicated:

1. To examine the resistance of reinforced concrete to sulphates and chlorides.
2. To develop and standardize new methods of testing of sulphate resistance of concrete.
3. To assess the impact of different concrete mixtures and their behavior when exposed to sulphate attacks.
4. To verify through a larger scope of work, within a larger range of materials, long term testing that contains permeability, creep, etc..

Acknowledgement

This work was recommended and counseled by Dr. Mohamed Naguib Abou-Zeid.

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