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Effect of Sulfate Attack on Mechanical Properties of Crumb Rubber Concrete

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ملخص البحث :

يهدف هذا البحث الى دراسة تاثير أملاح الكبريتات على الخواص الميكانيكية للخرسانة المحتوية على فتات مطاط الإطارات حيث تم صب ثلاثة خلطات تحتوي على نسب (0% -10%- 20%)من فتات مطاط الأطارات كنسبة من حجم الركام الناعم. تم غمر مجموعة من المكعبات فى أملاح كبريتات الماغنسيوم بتركيز 10% لمدة 90 – 180 – 365 يوم. تبين من النتائج أن زيادة نسبة فتات مطاط الإطارت أدى الى أنخفاض الخواص الميكانيكية للخرسانة وزيادة النفاذية.كما أظهرت النتائج أنخفاض مقاومة الخرسانة المغمورة فى أملاح الكبريتات مع ازدياد نسبة الأنخفاض مع زيادة مدة التعرض للأملاح.

Abstract :

The purpose of this paper is to investigate the behavior of Crumb Rubber Concrete (CRC) exposed to a sulfate environment. The mixtures have been produced by replacing the fine aggregate with crumb rubber at designated replacement levels of zero, 10%, and 20% by total fine aggregate volume. These concretes were immersed in 10% $MgSo_4$ solutions for 90, 180, and 365 days. Several tests were carried out to study the effect of crumb rubber on concrete properties such as slump test, compression test, split tensile test, flexural test, and permeability test. The evaluation of sulfate resistance was done by the determination of compressive strength. The experimental results indicated that increasing the rubber content led to a decrease in mechanical properties of concrete and an increase in water permeability**. The compressive strength for specimens submerged in sulfate solution decreased with increased rubber content, and also decreases by increase the curing age.**

Keywords :Crumb rubber, mechanical properties, permeability, sulfate attack

INTRODUCTION

Due to the growth of vehicle number increases, produced waste tires will be increased and the disposal of waste tires has been a major issue [1]. Globally, around 1.5 billion tires of tire waste are produced every year. [2]. Using recycled rubber waste shredded tires in concrete is a viable alternative studied by many researchers into three categories according to the particle size: chips, crumb rubber, powder rubber, and fibers [3,4, and 5]. Moustafa and ElGawady [6] studied the effect of used waste tires rubber by 0%, 5%, 10%, 15%,

20%, and 30% volume replacement of sand in high strength concrete, results reported that the slump decreasing by 33%–83% as a result of increasing the crumb rubber content from 5% to 30% by sand volume compared to high strength concrete without a rubber. Several researches [4-7] studied the properties of fresh and hardened properties of crumb rubber concrete (CRC), results showed that by increasing the amount of rubber percentage, mechanical properties of the concrete will be decreased. This may be due to the weak adhesion between the cement paste and the rubber particles which leads to the formation of a weak interstitial transition zone (ITZ) between them. Mohammed and Adamu [8] reported that increasing the substitution of 20% and 30% fine aggregates with crumb rubber led to a decrease in compressive strength by 16.3% and 23.2%, respectively. Fernández-Ruiz et al. [9] reported that
the increasing amount of rubber powder by 2.5% and 5% CR replace as partial cement decreases compressive strength by 28% and 38.2%; respectively and decreases flexural strength by 23.3%–20%; respectively. Mishra and Panda [10] carried out experimental work to evaluate the mechanical properties of conventional and self-compacting concrete with the inclusion of 0 to 20 % rubber chips instead of coarse aggregate, the result indicated that the mechanical properties of self-compacting rubber concrete more than (CRC) at all ages, and the best results are recorded at a ratio 5% rubber chips both CRC and SCRC. Many scholars [11-13] focused on the mechanical performances of crumb rubber concrete, the use of crumb tires particles as coarse aggregates will significantly reduce the mechanical properties of concrete, but its usage in the granular and powdered form will minimize the loss in mechanical properties. Although there was a general reduction in compressive strength over conventional concrete, the strength is adequate for medium load-bearing structural elements.
Jokar, F [14] carried out experimental work to improve the mechanical properties of (CRC) by adding natural zeolite as partial replacement of cement, used crumb rubber ratios 5, 10, and 15% replaced the coarse aggregates by weight. The results revealed that at mixes containing 5% rubber, 15% zeolite, and 5% rubber, 10% zeolite respectively. Increase compressive strength and flexural strength. da Silva et al. [15] found that adding rubber in concrete by 10–50% replacement of natural sand for tire rubber led to improve abrasion resistance and decrease the density of concrete due to lower density of rubber aggregate than natural aggregate. Thomas and Gupta [17] mentioned that when the content of waste tire increases from 2.5% to 20%, water penetration depth increases by 0% to 22.5% to normal concrete. Several studies [16-20] have been investigated experimentally mechanical and durability properties of crumb rubber concrete, they reported that the increasing CR particle replacement percentage led to increasing water absorption of concrete. Jinhua et al. [20] reported that used crumbed tire rubber powder by 5% replacement by sand can improve resistance to sulfate attack of concrete, but too much rubber content results in decreasing its performance. Noor et al. [21] also observed that Low w/c ratio in the mix increases the resistance of chloride ion erosion of rubberized concrete. Thomas and Gupta [22] had mentioned that there was more loss in compressive strength of sulfate attacked specimens as the amount of crumb rubber was increased. At the water-cement ratio 0.4, the compressive strength loss at 91 days for the

control mix was 6.5% for the mix with 20% rubber. The loss in strength was very severe for the water-cement ratio of 0.5. The mix containing 20% crumb rubber had recorded a loss of 10.58% at 91 days. It was observed that better resistance to water absorption and carbonation was observed for mixes containing crumb rubber up to 12.5%. Mukaddas et al. [23] carried out experimental studies of rubberized fiber mortar (RFM) to study the water permeability and chloride and sulfate resistance of mixes with 10% to 30% treated Crumb Rubber. It is concluded that the sulfate resistance of RFM (rubberized fiber mortar) with less than 30% TCR (Treated Crumb Rubber) is acceptable. Xue and Shinozuka [24] performed an experimental investigation to study damping and dynamic behaviors of rubberized concrete used a small-scale column with a 15% rubber replacement ratio. The result was conducted that the damping ratio increased by 62%, and the seismic response acceleration of the structure decreased by 27% in crumb rubber concrete. The study demonstrated the possibility of using rubberized concrete to enhance dynamic performance and reduce the seismic response of concrete structures.

2. MATERIALS AND METHODS

2.1. Material

In this study, the concrete mixes were produced using Ordinary Portland Cement (CEM I 42.5) with specific gravity 3.15, initial and final setting time was 95 and 205 min, respectively, natural sand and crumb rubber as fine aggregate, and crushed basalt as coarse aggregate. Properties of used aggregates are shown in Table 1. Natural water with PH ≥ 7 was used for making concrete specimens with w\c = 0.45. Figure 1 shows the used crumb rubber and Figure 2 shows the sieve analysis of used aggregates according to (ECP203) [25].

Table 1: Properties of Coarse Aggregate (Basalt), Sand, and Crumb Rubber

Type of test	Coarse Aggregate	Fine Aggregate	Crumb Rubber
Absorption	2.0%	1.8%	2.0%
Specific Gravity	2.72	2.50	1.20
Unit Weight (t\m3)	1.70	1.72	0.57

2.2. Concrete Mix Proportions, Samples, and Experimental Program

The replacement of fine aggregates by crumb rubber is used to prepare concrete mix at different percentages of 0%, 10%, and 20% as shown in Table 2. A constant w/c ratio of 0.45 is considered. The substitution of fine aggregates with crumb rubber was made on a volume basis. Mixes were prepared and cast at lab temperature.

To investigate the fresh properties of the concrete slump and compaction factor tests were conducted according to (ECP203) [25]. The compressive strength test was conducted using a hydraulic compression testing machine on three 150 mm cube samples of each concrete mix after 28-day of curing as presented in Figure 3. The loading rate for the machine applied in compression was 0.6 N/mm2/sec. Figure 4 presents splitting tensile 3 cylinders (100*200 mm) casted and tested to calculate splitting tensile strength, loading rate for the machine was 0.03 N/mm2/sec. For each mix 3 prisms with dimensions of 100 × 100 × 500 mm were cast and tested to determine flexural strength with a loading rate of 0.06 N/mm2/sec illustrated in Figure 5. Figure 6 shows the permeability test of mixes, three concrete cubes of size 150 mm were cast, and after completion of 28-day curing. The water pressure of 0.5 N/ mm2 was applied for a duration of 72 h on the specimens. The depth of water penetration was measured after completion of 72 h. Three standard cylinders of height 300mm and diameter 150 mm casted to depicted stress-strain curves for crumb rubber concrete mixtures tested under central axial compression loading up to failure on the loading frame machine shown in Figure 7. For sulfate attack, six groups of cubes of size 150 mm were cast and tested compressive strength at 90, 180, and 365 days. Three groups with 27 cube specimens were casted for sulfate attack immersion in 10% $MgSo_4$ solution and three groups in the lab environment. The compressive strength was determined and compared with the compressive strength of samples in the lab environment after 90,180, and 365 days.

Table 2: Concrete Mixes

Mix	**Rubber replacement**	**Weight per Cubic Meter (kg / m^3)**			
		Water	**Cement**	**Coarse Aggregate**	**Fine Aggregate**
M0	0	180	400	1175	653
M10	10	180	400	1175	587.7
M20	20	180	400	1175	522.4

Figure 1: Crumb rubber

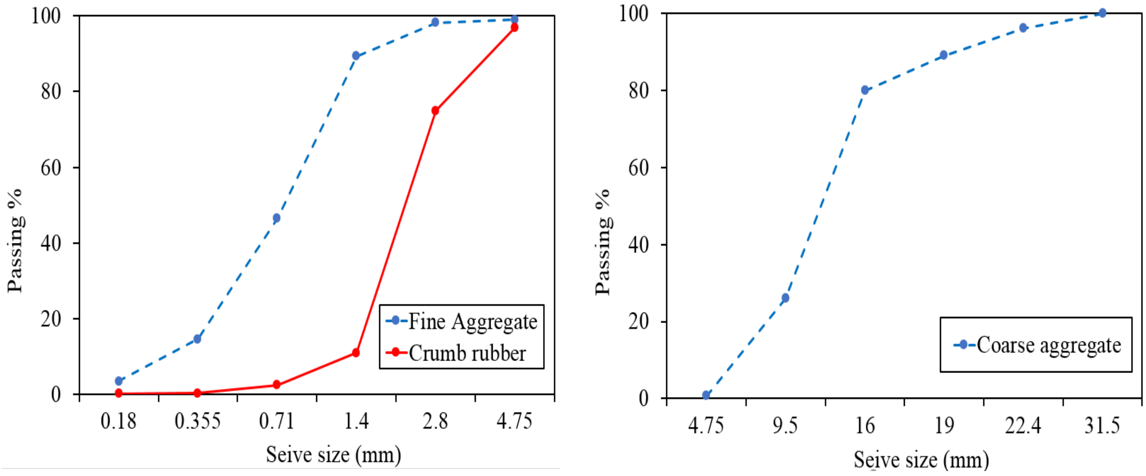

Figure 2: Sieve analysis of aggregates

Figure 3: Compression Test

Figure 4: Splitting Test

Figure 5: Flexural Test

Figure 6: Permeability Test

M0 M10 M20

Figure 7: Test Specimens

3. RESULTS AND DISCUSSION

Results of fresh properties, mechanical properties, and permeability for mixes are shown in Table 3

3.1 Fresh properties

The workability of concrete mixes was measured by doing a slump test and compacting factor test according to (ECP203). Table 3 shows the result of slump value and compacting factor of fresh concrete containing crumb rubber with different percentage, from the result it was observed that crumb rubber harm the workability of concrete.

Table 3: Fresh properties, mechanical properties, and permeability of concrete mixes

Mix code	Slump (mm)	C.F	Cube compressive strength (fcu) (MPa)	Cylinder compressive strength (fc`) (MPa)	Splitting tensile strength (MPa)	Flexural strength (MPa)	Elastic Modulus (GPa)	Permeability depth (mm)
M0	60	0.92	32.5	27.2	3.1	5.9	26.5	33.3
M10	40	0.87	29.3	25.1	2.7	5.7	25.1	40.2
M20	35	0.89	25.3	21.2	2.4	5.1	23.8	44.8

3.2 Compressive Strength

Figure 8 shows the 28-day compressive strength of concrete with and without crumb rubber aggregate at varying proportions. It has been observed that compressive strength decreases with an increase in the percentage of crumb rubber. This is due to lower adhesion between rubber and cement paste which results in the rapid rupture of concrete at the time of loading. The mix incorporation of 10% and 20% crumb rubber in concrete as an alternative to fine aggregates results in a decrease in strength by 9.7% and 22% respectively compared to the control mix. The results of compressive strength are given in Table 3.

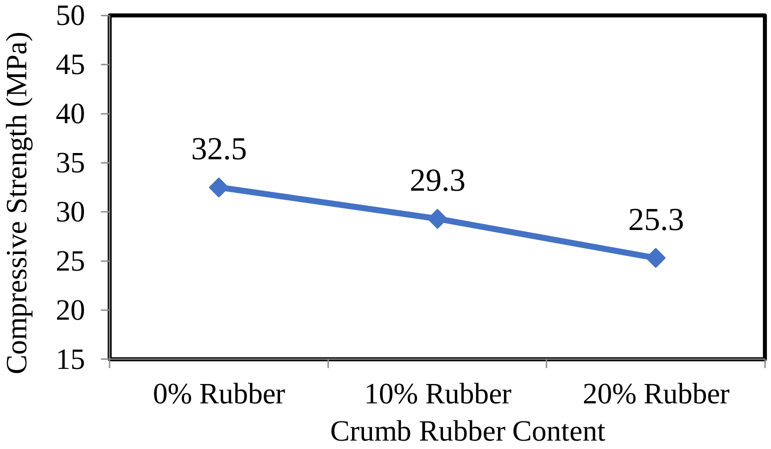

Figure 8: Compressive Strength at 28 days

3.3 Splitting Tensile Strength

Figure 9 and Table 3 show the splitting-tensile strength of CRC which illustrates that the splitting tensile strength is decreased by 13% and 22.6% with the addition of 10% and 20% of crumb rubber aggregate replacement sand; respectively. The splitting tensile strength was weakened due to the distribution of rubber particles in the concrete mixture is non-homogenous, due to the lower specific gravity compared to other materials.

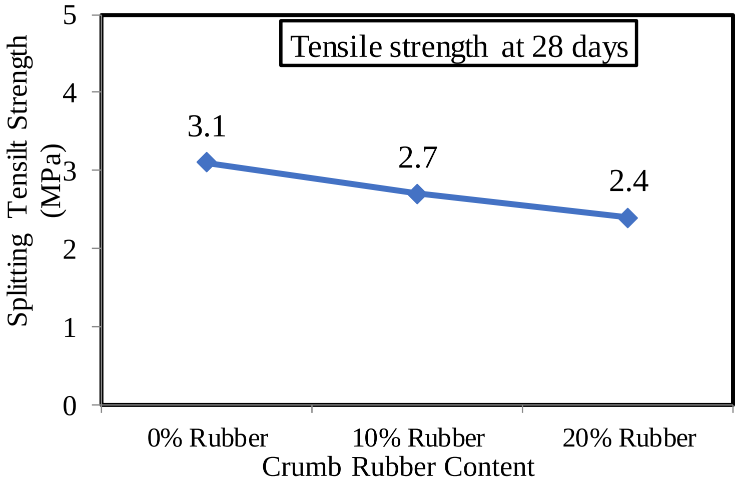

Figure 9: **28-day Splitting Tensile strength**

3.4 Flexural Strength

As shown in Figures 10, the flexural strength of rubberized concrete is lower than the normal concrete. It has been observed that the flexural strength of crumb rubber concrete decreases, as the percentage of crumb rubber in the concrete increases. Flexural strength for mix inclusion 10% and 20% crumb rubber were lower than the control mix by 3.4% and 13.5%; respectively. Due to lower adhesion between rubber and cement paste.

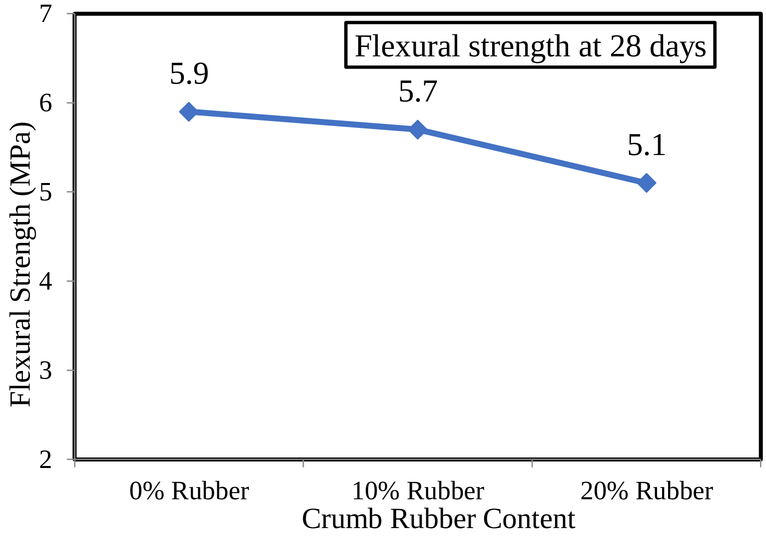

Figure 10: 28-day flexural strength

3.5 Permeability

Water permeability is the prime factor that influences the durability of concrete. the water permeability was calculated in terms of the depth of water penetration, as shown in Figures 11. Table 3 illustrates that mixes inclusion with 10% and 20% rubber aggregate as sand replacement in concrete, have shown an increase of permeability by 20.7% and 34.5%; respectively. Water permeability of crumb rubber concrete increased due to the generation of voids between the crumb rubber and cement matrix which allows the water to penetrate to greater depths in concrete.

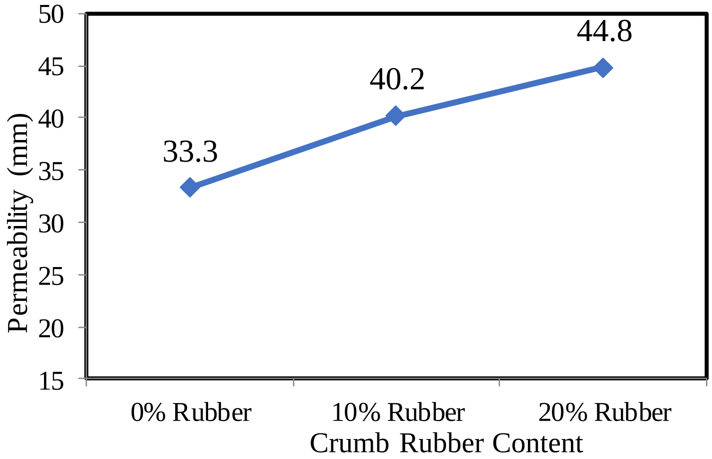

Figure 11: **Water permeability of mixes**

3.6 Stress-Strain Curve

Table 3 present the results of elastic modulus for mixes. The modulus of elasticity represented the deformation capacity of concrete, elastic modulus reduced by 5.3%, and 10.2% for mix incorporation with 10% and 20% rubber; respectively at 28 days to natural concrete. Figure 12 presents the stress-strain relationship for mixes. Many reasons are accounting for the lower strength of crumb rubber concrete [26]. Firstly, the adhesion of rubber particles and cement paste is weaker than the mineral aggregate. Secondly, the distribution of rubber particles in the concrete mixture is non-homogenous, due to the lower specific gravity compared to other materials.

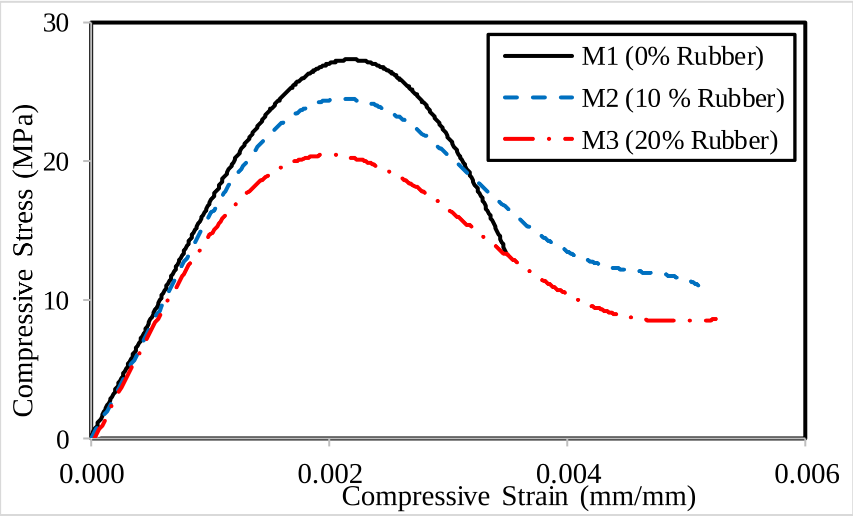

Figure 12: Stress-Strain Curve

3.7 After Exposed to sulfate Environment

The results of the compressive strength of specimens were subjected to lab and sulfate environment salt solution (10 % $MgSo_4$) after 90, 180, and 365 days are present in Table 4. Figure 13 shows the relation between exposure time to the compressive strength of CRC in a lab environment, it was observed that compressive strength increases with increasing curing age, also observed that compressive strength of concrete decreased with the increasing percentage of crumb rubber. The compressive strength loss at 90 days for the control mix was 6.5% and 20.3% for the mix containing 10% and 20% crumb rubber in the lab environment. The incorporation of 10% and 20% crumb rubber in concrete as an alternative to fine aggregates results in a decrease of compressive strength by 4.8% and 17.7%; respectively as compared to the reference mix without crumb rubber at a period of 180 days in a lab environment. At the age of 365 in the lab environment the reduction in compressive strength was 10.8% and 20.1% for specimens with 10% and 20% rubber; respectively. Figure 14 presents the relation between exposure time and compressive strength of CRC in a sulfate environment. It was observed that after 90 days of exposure to 10% magnesium sulfate $MgSo_4$ the percentage of reduction in compressive strength the specimens incorporation of 0%, 10%, and 20% crumb rubber was 9.3 %, 15.2%, and 26%; respectively, the percentage of decreasing in compressive strength of specimens inclusion with 0%, 10%, and 20% rubber after duration 180 days submerged in sulfate solution was 18.3%, 25%, and 32.6%; respectively, and after 365 days of immersion in sulfate solution the reduction in compressive strength of specimens inclusion with 0%,10%, and 20% rubber aggregate replacement sand was 35.2%, 41%, and 48.2%; respectively. The reduction in compressive strength increased with the duration of immersion in the sulfate solution. Figures 15, 16, and 17 presents compared between specimens inclusion with 0%, 10%, and 20% crumb rubber in lab and sulfate environment with curing age 90, 180, and 365 days.

Table 4: Compressive Strength for Average 3 Cubes at 90, 180, 3650 Days

Specimen ID	Crumb Rubber content	Compressive strength (MPa)			Environment
		90 days	180 days	365 days	
Group1	0%	33.4	34.9	39.8	Lab.
Group 2	10%	31.2	33.2	35.5	Lab.
Group 3	20%	26.6	28.7	31.8	Lab.
Group 4	0%	30.3	28.5	25.8	Sulfate salt
Group 5	10%	28.3	26.2	23.5	Sulfate salt
Group 6	20%	24.7	23.5	20.6	Sulfate salt

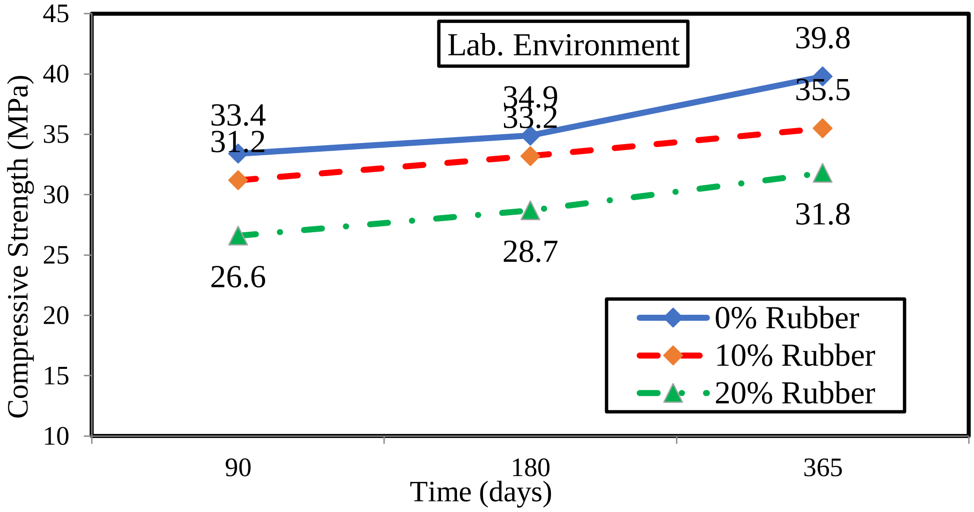

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Figure 13: Relation between exposure time to the compressive strength of CRC in the lab environment.

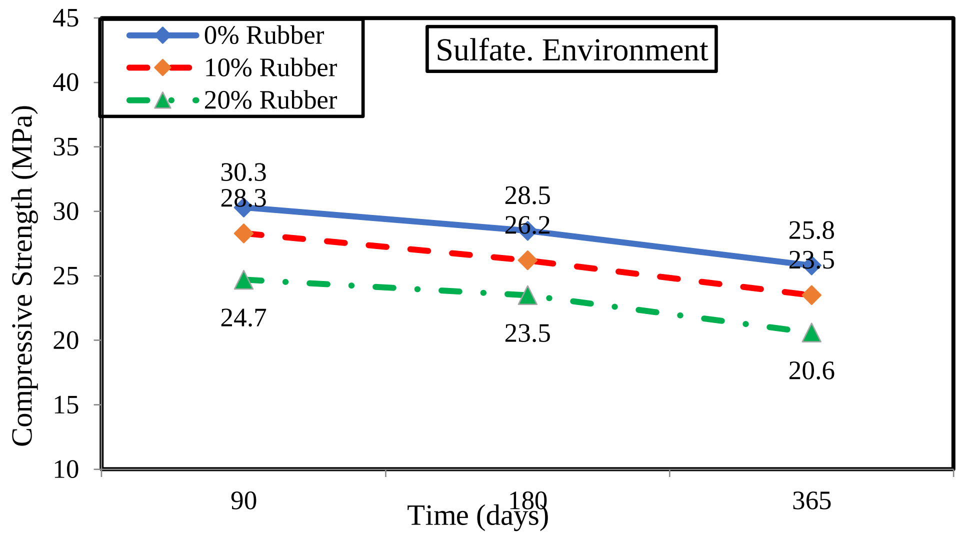

Figure 14: Relation between exposure time to the compressive strength of CRC in the sulfate environment.

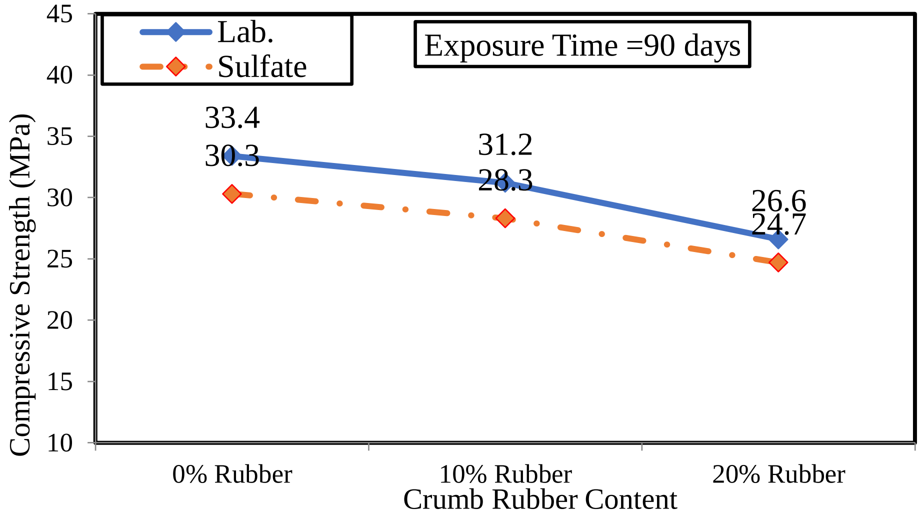

Figure 15: Comparison between compressive strength in lab and sulfate environment with different rubber ratio after exposure time 90 days.

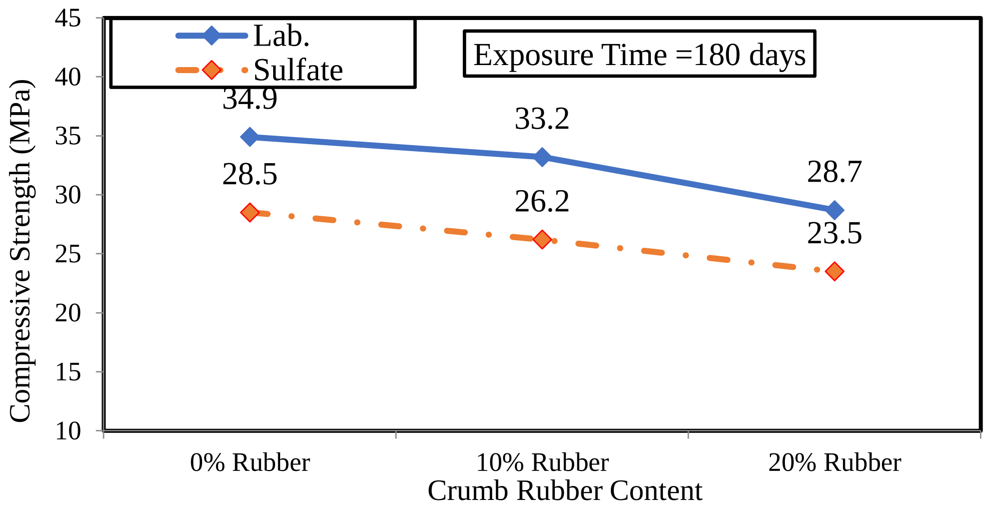

Figure 16: Comparison between compressive strength in lab and sulfate environment with different rubber ratio after exposure time 180 days.

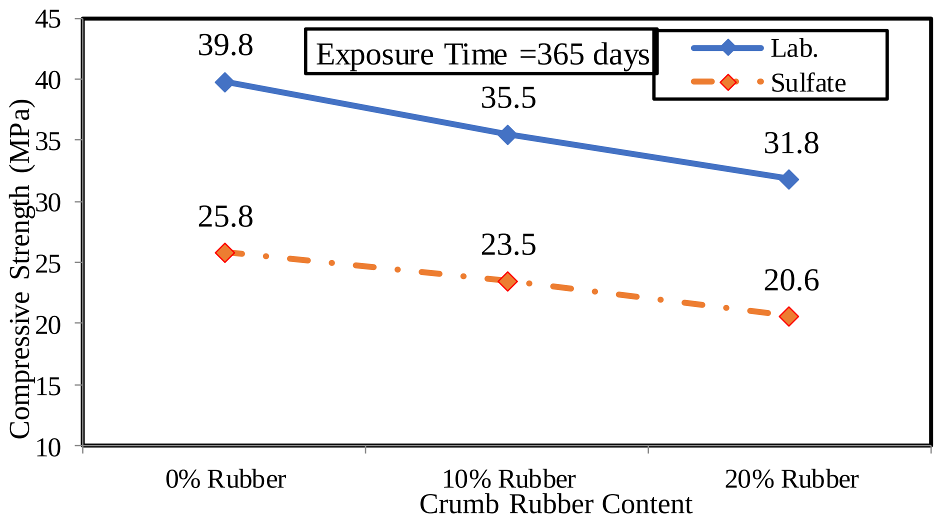

Figure 17: Comparison between compressive strength in lab and sulfate environment with different rubber ratio after exposure time 365 days.

Figure 18: Specimens before and after immersion in $MgSo_4$

4. CONCLUSION

This study presents the results of experimentally replacing fine aggregate in concrete mixes with crumb rubber. Based on **laboratory test results,** the following conclusions can be drawn:

Due to the fineness of crumb rubber, the workability of crumb rubber concrete decreases with the increase in crumb rubber content.

The compressive strength of rubberized concrete was lower than normal concrete. The result recorded a decrease in compressive strength by 9.7% and 22.0% for the mix with 10% and 20% crumb rubber; respectively.

Using rubber aggregate in concrete as replacement sand harmed its mechanical properties, by increasing rubber content, the reduction of strength increased. For mix with 10% and 20% crumb rubber tensile strength reduction by about 13% and 22.6% respectively.

It can be deduced from the results that the flexural strength shows reduction with an addition in the proportion of crumb rubber content. With the incorporation of 10% and 20% crumb rubber, strength decreases by 3.4% and 13.5%; respectively.

water permeability of rubberized concrete increases with increase substitution level of crumb rubber, as a result of generation voids of crumb rubber, which have led to greater water penetration.

Compressive strength for the specimens in the lab environment increased with increasing curing age, but in the sulfate environment, compressive strength decreased by the duration submerged in salts for natural and CRC concrete.

Compressive strength for concrete without rubber exposed to sulfate solution after 90, 180, and 365 days decreased by 9.2%, 18.3%, and 35.2%; respectively. The reduction in strength of the specimens with the incorporation of 10% rubber after 90,180 and 365 days of exposure to sulfate solutions was 15.2%, 25%, and 41% respectively.

A higher reduction in compressive strength was noted in specimens inclusion 20% crumb rubber immersed in 10% MgSo4 solution for 365 days.

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