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Experimental Evaluation of Untreated and Pretreated Crumb Rubber Used in Concrete

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Abstract: The present research aims at evaluating the mechanical performance of untreated and treated crumb rubber concrete (CRC). The study was also conducted to reduce the loss in mechanical properties of CRC. In this study, sand was replaced with crumb rubber (CR) with 0%, 5%, 10%, 15%, and 20% by volume. CR was treated with NaOH, lime, and common detergent for 24 h. Furthermore, water treatment was also carried out. All these treatments were done to enhance the mechanical properties of concrete that are affected by adding CR. The properties that were evaluated are compressive strength, indirect tensile strength, unit weight, ultrasonic pulse velocity, and water absorption. Compressive strength was assessed after 7 and 28 days of curing. The mechanical properties were decreased by increasing the percentage of the CR. The properties were improved after the treatment of CR. Lime treatment was found to be the best treatment of all four treatments followed by NaOH treatment and water treatment. Detergent treatment was found to be the worse treatment of all four methods of treatment. Despite increasing the strength it contributed to strength loss.

Keywords: crumb rubber concrete; crumb rubber; NaOH treatment; lime treatment; water treatment; detergent treatment; concrete; compressive strength; materials; mechanical properties

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1. Introduction

With the rapid growth in industrialization, solid waste is also increasing at an alarming rate. It has become essential for the construction industry to find and apply new technologies to reduce waste produced by the industries and incorporate it in conventional concrete [1–3]. Among many other solid wastes, crumb rubber (CR) is perhaps one of the most challenging solid waste materials to cope with. CR is made by shredding tires having a size between 0.075 mm and 4.75 mm [4]. It is estimated that nearly 1 billion tires are generated every year, ending their serviceable life and out of this, about 50%, without any treatment goes to garbage or landfills. By 2030, it is estimated, there would be about 5 billion tires that will be disposed of [5]. About 300 million tons are generated in the USA, 10 million tons in Turkey and Iran, and in the European Community, it is about 3.4 million tons [6]. In order to avoid the negative and harmful ecological and environmental effects caused by waste tire disposal, a significant body has promoted its use in concrete. The major part of wasted tires is landfilled, globally. This rapid accumulation of tire waste has catastrophic ecological and environmental consequences, causing serious threats to human health (e.g., soil contamination, fire, and pests) [7,8]. There is a great potential in the construction industry to accumulate a larger part of the rubber by utilizing CR as a partial replacement of natural aggregates in concrete which results in a type of concrete named, crumb rubber concrete (CRC) [9,10]. Introducing CR into concrete increases energy dissipation, impact resistance [11], drying shrinkage [12], water absorption [13], ductility [14], damping ratio, durability, and toughness [1,10,15]. However, it has been found by many researchers that by increasing the percentage of CR the compressive strength of the concrete decreases [16–20].

The utilization of admixtures in concrete has led to some changes in concrete mix design, but in return, the resulted concrete is more durable and stronger [21,22]. Adhesion of rubber particles is the main cause of strength loss [23,24]. In order to recover strength loss, many researchers have tried diverse methods and techniques. Some researchers have concentrated on the treatment of CR in order to improve adhesion, some have used additives to recover the strength loss, and some have used a combination of treatment of CR with additives to recover strength loss by adding CR [25]. Metakaolin, fly ash and silica fume are the most common additives used in CRC [6,10,22,26–30] and treatments; NaOH treatment is the most common treatment [10,31,32]. Some researchers have increased the cement content [10] and some have used different water to cement ratios [16,33] in order to mitigate the strength losses. Eshmaiel Ganjian et al. [34], investigated the performance of concrete by incorporating discarded waste tire replacing fine (200–850 mm) aggregate with 5%, 7.5%, and 10% by weight. They found a 10–23% drop in the compressive strength of the concrete while the drop in tensile strength was found to be 30–60%. Eldin and Senouci [35] found a reduction of 85% in compressive strength when coarse aggregate was replaced while with the replacement of fine aggregate, there was a 65% drop in the compressive strength. Güneyisi et al. [36] investigated the performance of CRC with the addition of silica fume. They used CR for fine aggregates and tire chips for coarse aggregates. They found a 77% reduction in the unit weight of the normal weight concrete with 50% replacement of rubber as the total aggregate volume. They also found that silica fume was beneficial and helped to recover strength loss. They also proposed that rubber should not be used above 25% of the total volume of aggregate. Rezaifar et al. [6] found that loss in compressive strength of CRC with 10, 20, and 30% CR replacement was 17, 34, and 51% respectively. Rezaifar et al. [6], used metakaoline in conjunction with CR which lowered the strength loss to about 22%. They also found a decrease in the unit weight of the CRC. Mohammadi et al. [31], recovered a 25% of strength loss by treating CR with NaOH for periods of 20 min, 24 h, and 7 days. They found 24 h to be the optimum period. Onuaguluchi and Panesar [17] investigated the performance of CRC with pre-coated CR in conjunction with silica fume. They found an increase in compressive strength of 29% with 5% CR and silica fume and an increase in compressive strength of 14% with 10% CR and silica fume. Youssf et al. [10], investigated the performance of concrete by treatment using silica fume, NaOH (sodium hydroxide) solution, and cement content. They found 0.5 hours of treatment of rubber, 350 kg/m^3 cement content, and 0% silica fume replacing cement by weight as the best alternatives.

In this study, the focus is on the surface treatment of the CR to mitigate the strength loss of concrete due to the addition of CR rather than focusing on additives, admixtures, or increasing the cement content in the CRC. This study aims at finding new, better, and cheaper methods of surface treatments of CR to recover the strength loss of concrete by adding CR. This research study will contribute in better understanding the relationship between surface treatments of CR and mechanical properties of the CRC. This will pave the way to explore and advance the treatments' techniques in order to achieve the best results relating to losses in mechanical properties of CRC. The outcomes of this research study can be helpful in the practical application of using CR in conventional concrete.

2. Experimental Program

A total of 189 cylinders of 150 mm × 300 mm for 21 mixes (as shown in Table 1) were made for the research study. For each mix, nine cylinders were made. Three for assessing compressive strength at 7 days, three for assessing compressive strength at 28 days, and three for assessing the indirect tensile the strength at 28 days. Out of the 21 mixes, 1 mix was used for controlled mix, 4 mixes were for untreated CRC, and 16 mixes were for treated CRC as shown in Table 1. About 15 additional cylinders of 150 mm × 300 mm were made to evaluate the compressive strength of untreated CRC at 28 days after placing the concrete specimen in the oven at 200 °C for a time period of 6 hours. The specimen were then allowed to cool down at room temperature.

Table 1. Mix design.

Mix Type	Treatment	CR %	w/c Ratio	Net Water (kg/m^3)	Cement (kg/m^3)	Fine Aggregate		Coarse Aggregate
						Sand (kg/m^3)	Crumb Rubber (kg/m^3)	Gravel (kg/m^3)
C0 (CM)	-	0	0.50	203.97	400	661.82	0	1074.18
CU5	-	5	0.50	203.96	400	628.73	20.35	1074.18
CU10	-	10	0.50	203.95	400	595.64	40.70	1074.18
CU15	-	15	0.50	203.94	400	562.55	61.05	1074.18
CU20	-	20	0.50	203.93	400	529.46	81.40	1074.18
CN5	NaOH	5	0.50	203.96	400	628.73	20.35	1074.18
CN10	NaOH	10	0.50	203.95	400	595.64	40.70	1074.18
CN15	NaOH	15	0.50	203.94	400	562.55	61.05	1074.18
CN20	NaOH	20	0.50	203.93	400	529.46	81.40	1074.18
CL5	Lime	5	0.50	203.96	400	628.73	20.35	1074.18
CL10	Lime	10	0.50	203.95	400	595.64	40.70	1074.18
CL15	Lime	15	0.50	203.94	400	562.55	61.05	1074.18
CL20	Lime	20	0.50	203.93	400	529.46	81.40	1074.18
CW5	Water	5	0.50	203.96	400	628.73	20.35	1074.18
CW10	Water	10	0.50	203.95	400	595.64	40.70	1074.18
CW15	Water	15	0.50	203.94	400	562.55	61.05	1074.18
CW20	Water	20	0.50	203.93	400	529.46	81.40	1074.18
CD5	Detergent	5	0.50	203.96	400	628.73	20.35	1074.18
CD10	Detergent	10	0.50	203.95	400	595.64	40.70	1074.18
CD15	Detergent	15	0.50	203.94	400	562.55	61.05	1074.18
CD20	Detergent	20	0.50	203.93	400	529.46	81.40	1074.18

2.1. Concrete Materials and Properties

Ordinary Portland Cement (OPC) in compliance with ASTM C150 Type I, from Bestway cement factory was used. The sand was used as fine aggregate, crushed stone was used as coarse aggregate, and CR was used as a replacement of sand by volume ranging from 0–20%. Water used for the entire research project was ordinary tap water available. The fineness modulus of fine aggregate was found to be 2.71. The specific gravity, water absorption, and moisture content of the sand were 2.6, 1.71%, and 0.809% respectively. The coarse aggregates with a maximum size of 22.5 mm were used. The specific gravity, water absorption, and moisture content of coarse aggregate were 2.63, 0.431%, and 1.696% respectively. The specific gravity, water absorption, and moisture content of CR were found to be 1.599, 0.035%, and 0.085% respectively. The sieve analysis of CR, fine and coarse aggregates are shown in Table 2.

NaOH and lime were obtained from the local markets. Lime was in powdered form while NaOH was available in bottles of 1 kg in solid granular form. The detergent used in this research study was locally available detergent used for washing clothes. CR was collected from a CR supplier. CR was in ground form with particle size ranging from 4.75–0.075 mm in size.

Table 2. Sieve analysis of aggregates.

Sieve Size (mm)	0.075	0.15	0.3	0.6	1.18	2.36	4.75	9.5	12.5	19
Sand Passed (%)	0	3.8	11.9	36	77	94.8	99.4	100	100	100
Crumb Rubber (%)	-	0	3.6	23	43.6	68	99.7	100	100	100
Gravel Passed (%)	-	-	-	-	-	-	-	28.62	67.12	92.02

2.2. Mix Proportions

Mix design of controlled concrete was prepared according to British Standard (BS) i.e., in per cubic meter of concrete as presented in Table 1. Controlled concrete was designed for compressive strength of 21.7 MPa. Controlled concrete was the concrete having 0% CR. Water to cement ratio (0.5), cement content (400 kg/m^3), and coarse aggregate (1074.18 kg/m^3) were not changed throughout the study. In this study CM stands for controlled mix concrete, CN for NaOH treated, CL for lime treated, CW stands for water treated, and CD stands for detergent-treated CRC. Whereas 5, 10, 15, and 20 represent percentages of sand replaced with CR by volume.

2.3. Treatment of Crumb Rubber

Researchers have tried treatments of CR to improve the adhesion properties in order to improve the strength of concrete [37–40]. In this research project, four different types of treatments were used to treat the CR's surface namely lime treatment, NaOH treatment, detergent treatment, and water treatment in order to make the surface rougher and improve the interface adhesion of rubber/cement.

In the present study, 10% concentrated solutions of NaOH, detergent, and lime were made to treat the CR. Untreated CR was washed and then submerged in the solutions for 24 h. The time of treatment was taken on the basis of contact of CR with the solutions which was 24 h. After the time has elapsed, CR was extracted from the solutions and washed again to decrease the pH values as it may cause adverse effects on the concrete [10]. Water treatment was carried out by boiling the water and then submerging CR into it for a time period of 10 minutes. Then the water was allowed to cool and the CR was removed from the water. This treatment was done to remove zinc stearate layers on CR [41].

2.4. Specimen Preparation

The concrete batches were mixed in the laboratory with the help of a mixer in accordance with ASTM C192/C192M [42]. After uniform mixing, each specimen was cast in 150 $\times$ 300 mm cylinders and compacted with the help of a rod vibrator. After casting, the specimen were left at room temperature 24 $\pm$ 3 °C for a time period of 24 h. The specimen were then withdrawn from the molds and kept for curing in the tank until the time of testing at a temperature of 24 $\pm$ 3 °C in accordance with ASTM C192/C192M [42].

2.5. Testing Methods

Slump test was conducted according to ASTM C143 [43] and compaction factor test was conducted following IS: 1199–1959 [44]. The compressive strength of each mix was determined according to ASTM C 109M [45] and C 39 [46]. Testing was carried out at the curing age of 7 and 28 days. An indirect tensile strength test was conducted following AS 1012.10 [47] at a constant loading rate of 1.5 $\pm$ 0.15 MPa/min at 28 days of curing. Ultrasonic pulse velocity test was also performed according to ASTM C597 [48] at 28 days of curing. The water absorption test was performed in accordance with ASTM C642 [49] specifications. The weight of the concrete cylinders was obtained and divided by the volume of molds. The unit weight of concrete for all cylinders was assessed at 7 and 28 days.

3. Results and Discussions

In this section effect of untreated CR, NaOH treated CR, lime-treated CR, detergent-treated CR, and water-treated CR on water absorption, slump, compressive strength, and indirect tensile strength of concrete are discussed. Experimental results of all concrete mixes are shown in Table 3.

Table 3. Test results.

Mix Code	Treatment	CR %	Slump (mm)	Compressive Strength (MPa)		Indirect Tensile Strength (MPa)	Water Absorption (%)		Unit Weight (kg/m^3)		UPV (km/s)
				7 days	28 days		7 days	28 days	7 days	28 days	
CM	-	0	50	11.88	23.00	7.30	2.3	6.6	2331	2464	4.45
CU5	Untreated	5	50	11.00	20.63	7.04	1.8	6.2	2344	2364	4.41
CU10	Untreated	10	75	9.56	15.37	5.33	2.8	6.8	2121	2128	4.41
CU15	Untreated	15	150	6.62	11.45	3.60	3.6	7.4	1999	2021	4.40
CU20	Untreated	20	180	4.21	8.71	1.15	4.7	8.7	1882	1892	4.38
CN5	NaOH	5	65	11.82	21.40	7.19	4.7	3.7	2370	2382	4.41
CN10	NaOH	10	90	10.10	16.52	5.68	5.8	4.1	2117	2132	4.40
CN15	NaOH	15	150	7.25	12.25	3.95	8.0	4.9	1989	2014	4.39
CN20	NaOH	20	165	5.63	9.31	1.76	8.6	5.3	1869	1881	4.37
CL5	Lime	5	50	12.01	21.56	7.33	1.1	3.1	2341	2375	4.42
CL10	Lime	10	75	10.37	16.67	5.91	2.3	3.9	2101	2110	4.41
CL15	Lime	15	165	7.43	12.48	4.05	3.3	3.9	1903	2021	4.40
CL20	Lime	20	180	5.87	9.78	1.82	4.5	4.1	1875	1882	4.39
CW5	Water	5	50	11.23	21.05	7.08	4.9	4.6	2353	2363	4.40
CW10	Water	10	75	9.91	16.43	5.41	6.2	5.5	2111	2124	4.40
CW15	Water	15	150	7.10	12.01	3.66	8.2	6.7	1993	2015	4.39
CW20	Water	20	180	4.52	9.25	1.17	10.2	7.3	1874	1890	4.37
CD5	Detergent	5	50	10.95	20.57	7.00	4.6	4.0	2352	2360	4.39
CD10	Detergent	10	90	9.40	15.32	5.29	5.6	4.3	2109	2121	4.38
CD15	Detergent	15	165	6.40	11.43	3.53	6.5	5.3	1992	2015	4.38
CD20	Detergent	20	180	4.15	8.71	1.14	7.9	6.5	1881	1892	4.36

3.1. Slump and Compaction Factor

The slump of freshly mixed concrete for replacement levels of 0%, 5%, 10%, 15%, and 20% determined (as shown in Figure 1) with the maximum slump of 180 mm was recorded for CU 20, CL20, CW20, and CD20. The minimum slump of 50 mm was recorded for CM, CU5, CL5, CW5, and CD5. On average an increase of 52% slump was recorded for every increment of 5% in CR replacement. A total of 250% increase in a slump was recorded with 20% of replacement of sand with CR from that of controlled concrete. Albano et al. [50] used CR (0.59 and 0.29 mm) as fine aggregate and found a decrease in a slump. Bignozzi and Sandrolini [51] replaced the sand with CR of two sizes 0.5 to 2 mm and 0.05 to 0.7 mm and found no significant change in the behavior of fresh concrete. However, Onuaguluchi and Panesar [17] replaced the sand with CR and found a significant increase in the slump.

A 14% increase in compaction factor was recorded with 20% replacement of sand by CR. On average there was a 3.3% increase in compaction factor for every increment of 5% replacement with CR.

The increase in a slump and compaction factor in this study was due to the addition of poorly graded CR in the mixes with a high fineness modulus of 3.62 as compared to sand which had the fineness modulus of 2.77. With the increase in fineness modulus of concrete aggregates, the workability of CRC also increased.

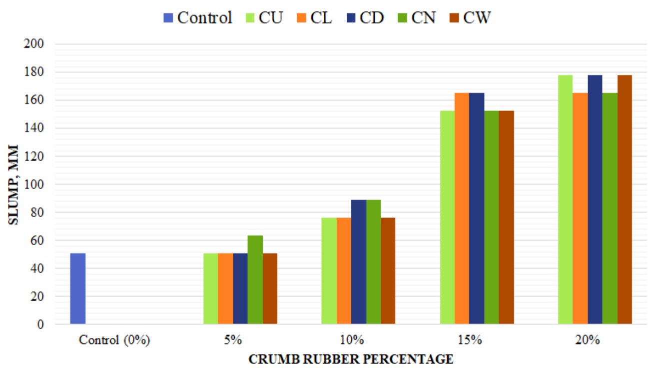

Figure 1. Slump test results.

The compaction factor of freshly prepared concrete at replacement levels of 0%, 5%, 10%, 15%, and 20% was determined as shown in Figure 2. Compaction factor increases with the increase in percentage levels of CR.

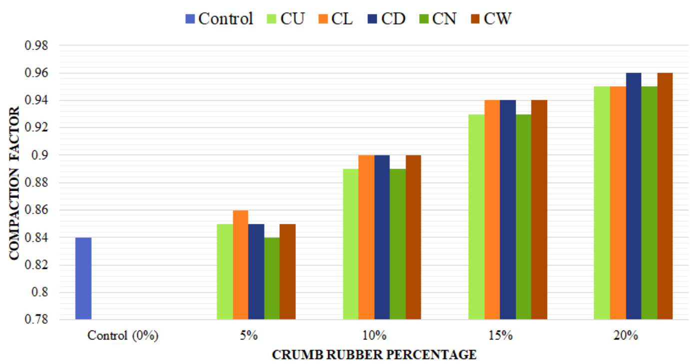

Figure 2. Compaction factor results.

3.2. Water Absorption

Water absorption tells us about the porosity and pore structure of the concrete. Sadek and El-Attar [52] found that water absorption is affected by CR when replaced with fine or coarse aggregates. However, they found that in the case of coarser rubber the increase in water absorption is greater as compared to the finer rubber aggregates. Water absorption was increased by increasing the percentage of the CR and was decreased by increasing the curing ages (as shown in Figures 3 and 4). The lowest absorption percentage was recorded at 1.15% for CL5 at 7 days and for 28 days it was 3.1% for CL5. The highest absorption percentage was recorded 10.23% for CW20 at 7 days and 8.69% for CU20 at 28 days. This increase in the water absorption was due to a decrease in unit weight and increase in porosity of CRC due to an increase in the percentage of CR.

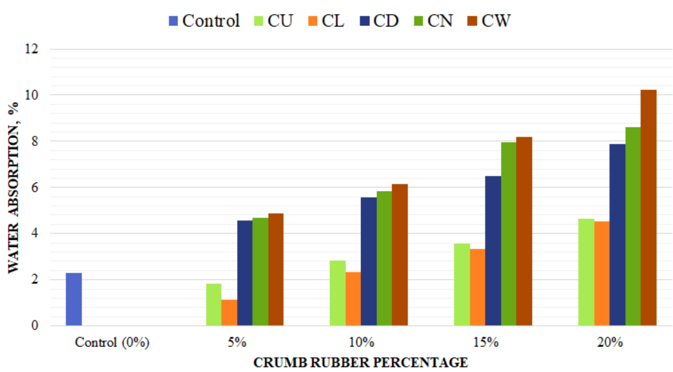

Figure 3. Water absorption at 7 days.

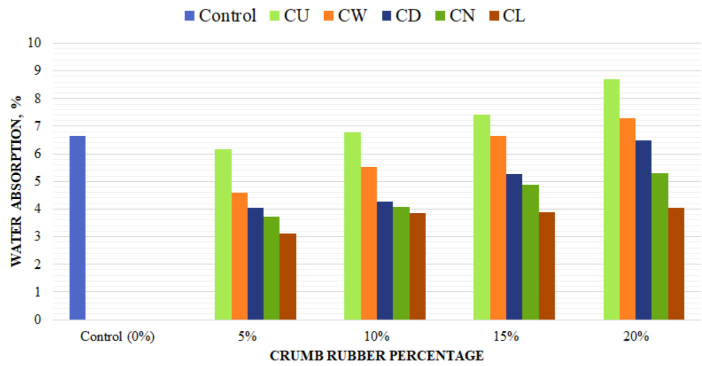

Figure 4. Water absorption at 28 days.

3.3. Density

As percentage levels of replacement of CR increased, the density was decreased. Corinaldesi et al. [53], has also found a decrease in density with the introduction of rubber particles. However, as the curing age increased, the density increased. The control mix showed an increase in the density from 7 to 28 days i.e., 2331 kg/m^3 to 2464 kg/m^3. The lowest amount of density recorded for CRC at 7 days was 1869 kg/m^3 and for 28 days it was 1881 kg/m^3 as shown in Figures 5 and 6 respectively. The increase in density as the curing period increased was due to the presence of water which helped internal curing. The water was available for the hydration of cementitious materials in concrete. The decrease in density as the replacement level increases was due to the low specific gravity of CR.

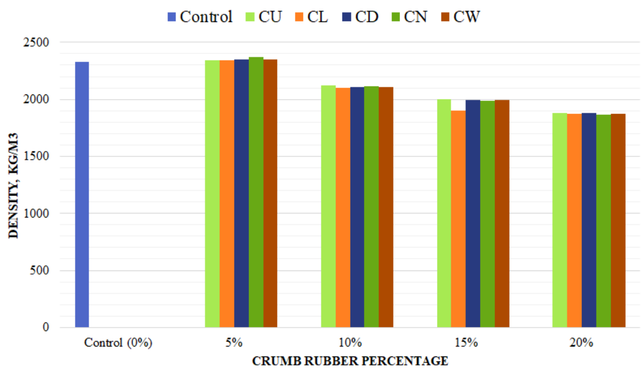

Figure 5. Density of concrete at 7 days.

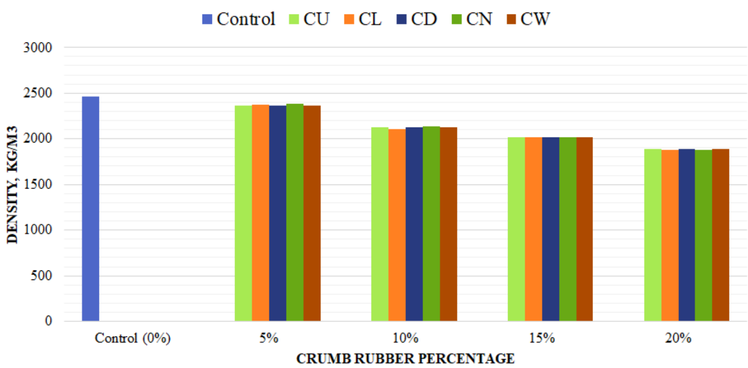

Figure 6. Density of concrete at 28 days.

3.4. Ultrasonic Pulse Velocity (UPV)

As the replacement level was increased there was a decrease in UPV values. Turgut and Yesilata [54] used CRs with sizes ranging from 4.75 mm (No. 4 Sieve) to 0.075 mm (No. 200 Sieve). They also found a decrease in UPV values with the increase in the percentage of CR. Salhi et. al [55] found a correlation between compressive strength and UPV to be good. The highest value of UPV was recorded for CL5 and it was 4.42 km/s which is a 0.67% decrease from that of controlled concrete. The lowest value of UPV was recorded for CD20 and it was 4.36 km/s which is a 2.02% decrease from that of controlled concrete. The UPV and density of the concrete share a direct relation. In this study, with the increase of CR, the density of the concrete was decreased as shown in Figure 7. It means the more the CR in the concrete; the more would be the cracks, pores, capillaries attributing to the enhancement of interfacial transition zone (ITZ) [56]. Due to the presence of pores, crack, and capillaries the values of UPV were decreased with the increase in the percentage of CR because it needs compact mass for the velocity of compression waves to travel.

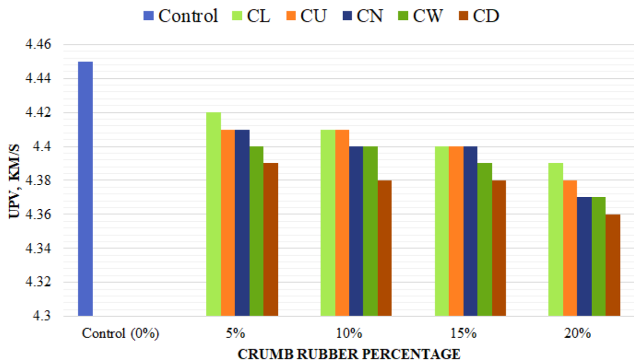

Figure 7. UPV results.

3.5. Compressive Strength

It is evident from many research studies that by increasing the percentage of CR the compressive strength of the concrete decreases [16–20,57,58]. There was a loss of 7.41% compressive strength at 7 days with 5% replacement, a loss of 19.53% with 10% replacement, 44.28% with 15% replacement, and a loss of 64.56% with 20% replacement of sand with CR in untreated CRC (Figure 8). At 7 days of curing, lime treatment managed to recover 9.96% of the strength loss, NaOH treatment recovered 7.54% of strength loss, and water treatment recovered 5.09% of strength loss at 7 days of curing. Detergent treatment did not recover strength loss however it decreased the strength further to 1.72% at 7 days of curing. At 28 days of curing 10.30% loss of compressive strength at 5% replacement, 33.17% at 10% replacement, 50.22% strength loss at 15% replacement, and 62.13% loss at 20% replacement of sand with CR were seen (Figure 9). At 28 days of curing, lime treatment managed to recover 8.56% of the strength loss, NaOH treatment recovered 6.27% of strength loss, and water treatment recovered 5.01% of strength loss at 28 days of curing. Detergent treatment did not recover strength loss, however it decreased the strength further to 0.20% at 28 days of curing. Figure 10 shows the comparison of strength loss recovered at 7 and 28 days respectively. It shows that the strength loss recovered or deteriorated for all treatments was greater at 7 days than 28 days except for water treatment.

3.6. Compressive Strength after Heating

Liang et al. [59] found a significant decrease in compressive strength of concrete after a rise in temperature. A greater drop in compressive strength of concrete samples was recorded at 28 days after placing them in the oven at 200 °C (Figure 11) as compared to the compressive strength at normal temperature (24 ± 3). Replacement of sand with CR showed very poor results when CRC was heated in the oven at a temperature of 200 °C. At 5% replacement level there was a loss of 61.38% in compressive strength, at 10% replacement, it increased to 87.13%, at 15% replacement, it further increased to 90.73%, and at 20% replacement level it reached 95.37%. This huge strength loss was due to the low softening point of CR which lies between 180 and 250 °C.

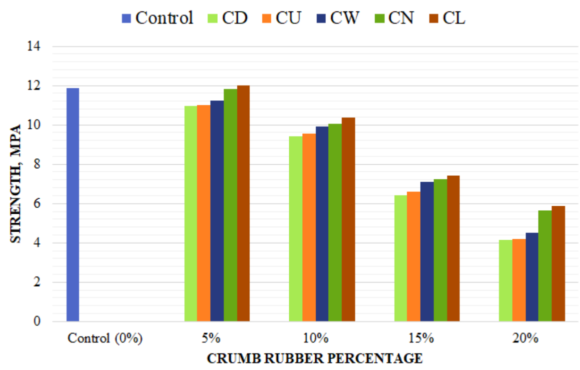

Figure 8. Compressive strength at 7 days.

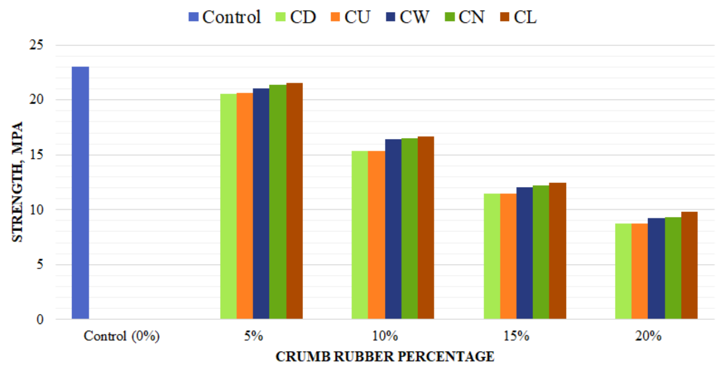

Figure 9. Compressive strength at 28 days.

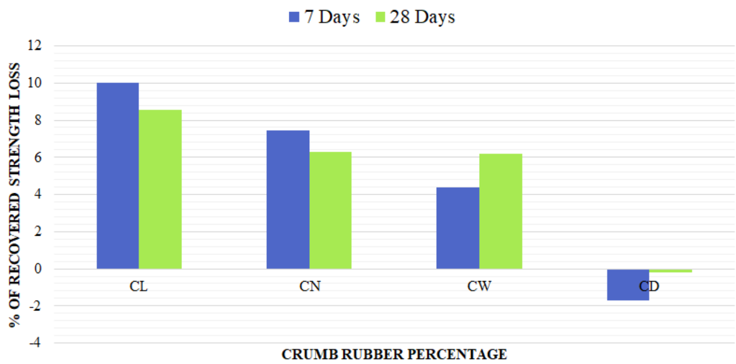

Figure 10. Percentage of recovered strength loss at 7 and 28 days.

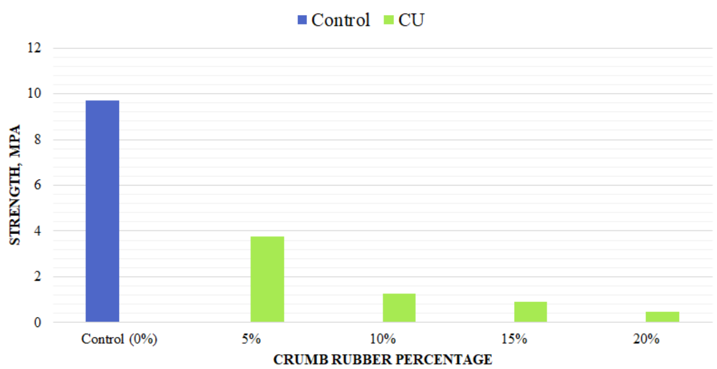

Figure 11. Compressive strength (after heating) at 28 days.

3.7. Indirect Tensile Strength

Indirect tensile strength was found to be following the same pattern of compressive strength. At 28 days of curing there was a loss of 3.56% in indirect tensile strength at 5% replacement, 24.25% loss at 10% replacement, 50.68% loss at 15% replacement, and 84.25% loss of indirect tensile strength at 20% replacement level of sand with CR (Figure 12). Batayneh et al. [8], also found that with the increase in CR, there is a loss in tensile strength of concrete. Lime treatment managed to recover 9.16% of strength loss, NaOH treatment recovered 6.14% of strength loss, and water treatment recovered 1.37% of strength loss. Detergent as in all cases reduced the tensile strength to a further 1.03%. The reduction in indirect tensile strength might be due to the weak bonding between CR and cement. The ITZ acted as a micro-crack between the two materials. This weak ITZ accelerated the reduction in tensile strength [60].

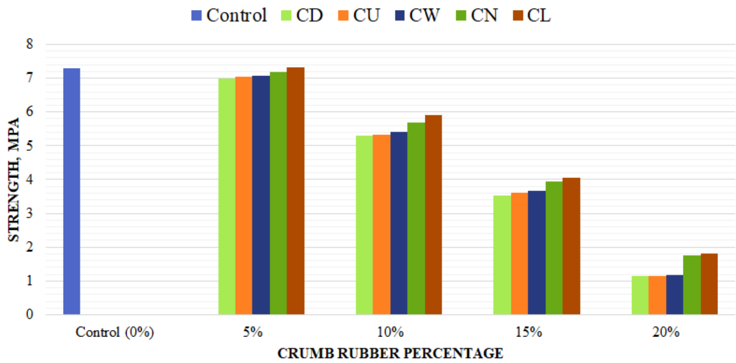

Figure 12. Indirect tensile strength at 28 days.

3.8. Scanning Electron Microscopy (SEM)

In order to check the morphology of CR, SEM was conducted on treated and untreated samples. SEM can render information on surface structure, chemical composition, crystalline structure, and electrical behavior of the top [61]. As the focus of this research was on surface treatments, SEM helped to look at the physical effects of surface treatments besides experimental results.

From Figures 13–17, it is visible that the surface of lime-treated CR is rougher than the remaining three giving the best results in the case of a compression test. After lime the surface of NaOH-treated CR is relatively rougher than water-treated and detergent-treated samples giving the second-best results. The surfaces of water-treated and detergent-treated CR were relatively slightly rougher than the untreated CR.

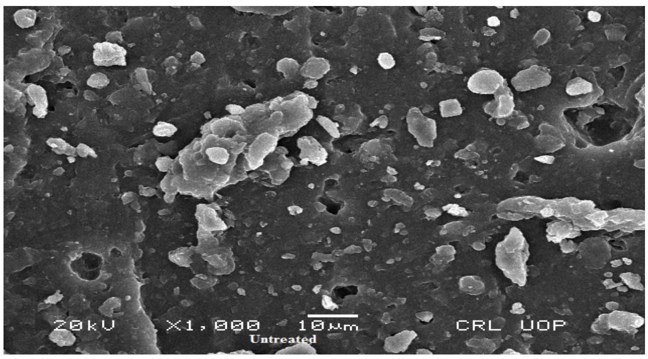

Figure 13. Untreated CR.

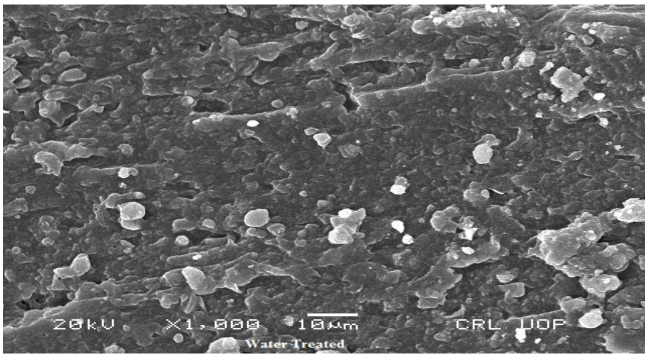

Figure 14. Water-treated CR.

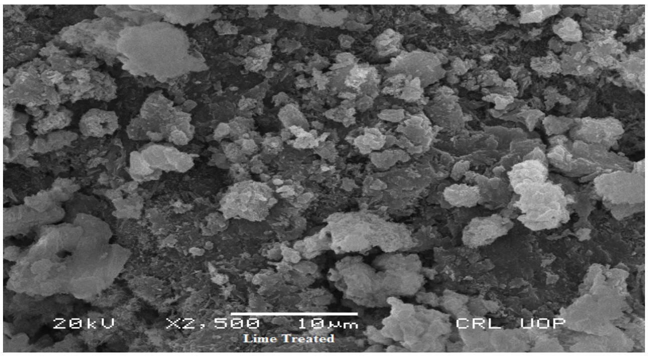

Figure 15. Lime-treated CR.

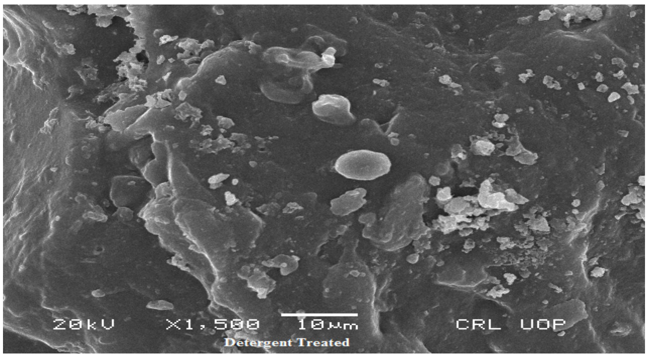

Figure 16. Detergent-treated CR.

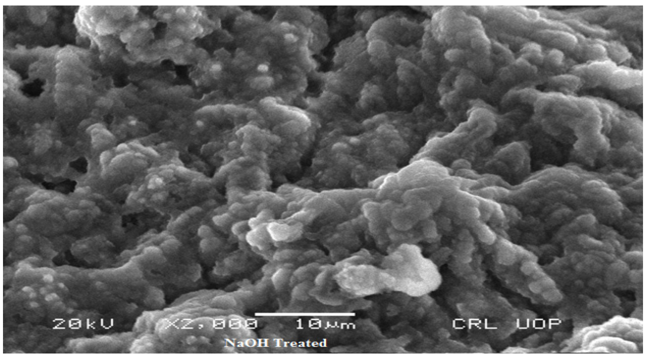

Figure 17. NaOH-treated CR.

4. Conclusions

This study was conducted to evaluate the performance of untreated and treated CRC. CR was treated with lime, NaOH, detergent, and water. The fresh and hard properties of concrete were evaluated. Based on the experimental results of the research study, the following conclusions are drawn:

- A 250% increase in slump and 14% increase in compaction factor were recorded with 20% replacement of sand with CR.
- Water absorption increased with the addition of CR and a maximum of 10.23% water absorption was recorded at 7 days for 20% replacement of sand and it decreased as the curing period increased and recorded 8.69% as the maximum value at 28 days.
- The density of concrete dropped to 1869 kg/m^3 and 1881 kg/m^3 for 7 and 28 days respectively for 20% replacement. Based on its lightweight properties CR concrete can be used in stone backing, interior construction, false facades, and nailing concrete.
- Lime treatment was found to be the best treatment of all four treatments followed by NaOH treatment and water treatment. Lime treatment recovered a compressive strength of 10.30% at 28 days and 9.16% of tensile strength at 28 days.
- Detergent treatment was found to be the worse treatment of all four treatment methods. Despite of increasing the strength it contributed to compressive strength loss of 1.70% at 7 days and 0.20% at 28 days and a loss of 1.03% for indirect tensile strength at 28 days.
- CRC is not suitable for heat applications as it dropped 95.37% and 61% of its compressive strength with 20% and 5% replacement of sand, respectively.

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