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A New Approach for Producing Sustainable Concrete by Incorporating Treated Waste Rubber

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Abstract

Recently, the increasing number of used tires in landfills has become a major issue. The tire waste is burned, which results hazardous gases that further affect the earth's natural ecosystem. The main objective of this research is to investigate the partial replacement feasibility of fine and coarse aggregates with treated crumb rubber on fresh and hardened characteristics of concrete. This is reducing the consumption of natural resources utilized in concrete. Total aggregates were replaced by crumb rubber (CR) in the concrete mixture at ratios of 2.5%, 5%, 7.5%, and 10% by volume. CR particles were treated by two methods, the first method is soaking in water and the second method is treating by placing CR particles in benzene. The findings indicated that the compressive strength decreased by 20%, 31.67%, 43.33%, and 53.33% than that of the reference mix at 28 days of curing in the case of water treatment, while it decreased by 10%, 16.67%, 33.33%, and 40% in the case of benzene treatment at the ratios of CR 2.5%, 5%, 7.5%, and 10%, respectively. The increase in CR content reduced the modulus of rupture of mixes by 11.6%, 20.9%, 34.9%, and 44.18% in the case of treating CR particles with benzene at ratios of CR 2.5%, 5%, 7.5%, and 10%, respectively. The modulus of elasticity decreased with a higher ratio of CR particles making concrete containing CR suitable for use in pavement, playgrounds, and machine bases. The mixture with the replacement of 2.5% CR of total aggregates and treated with benzene was considered the best mixture containing rubber as it had a little reduction in strength of compressive, modulus of rupture, and indirect tensile with comparison to the reference mix. When the ratio of CR particles was increased, the density of the mixtures decreased.

Keywords

Crumb rubber, compressive strength, indirect tensile strength, density, water absorption

1. Introduction

One of the main issues and a significant burden that developing countries face is the disposal of waste tires. Using crumb rubber (CR) on roads is one of the most important ways to dispose of it. Total aggregates were replaced by CR at ratios of 2%, 4%, 6%, 8%, and 10% by weight to assess the mechanical characteristics of concrete. The research methodology includes comparing the outcomes of treated and untreated CR. According to the results, by treating CR with chemicals, concrete for pavement can be obtained with the same characteristics as the control mix. The substitution of 2% and 4% crumb rubber provided sufficient pavement characteristics for utilization in the construction of highways [1]. Using crumb rubber particles enhances the workability of fresh concrete and reduces its density. As the amount of CR added rises, the mechanical characteristics of concrete often deteriorate. The compressive and modulus of rupture strength of concrete with crumb rubber is slightly higher than the concrete with natural aggregates. But it is only as strong as the size of CR particles that substitutes sand are fine and the ideal CR level for substitution (a ratio of CR from 0% to 10% raises compressive strength about 2%, and the modulus of rupture strength is improved about 7%-21% with a ratio of 10%-20% CR in mixtures). The rate of water absorption and permeability of CR concrete are greater than that of concrete with natural aggregates. However, blending various sizes of CR particles and using small ratios of CR from 2.5%–7.5% as a partial substitution of aggregates will lessen the concrete water absorption [2]. Crumb rubber was utilized to enhance the impact of normal concrete. Normal concrete needs to improve its properties for impact loads by using CR. However mechanical characteristics of CR concrete reduce but treatment of CR particles can improve this. There are various methods of treatment for CR such as chemical and thermal treatment which can improve adhesion between the surface of CR particles and cement paste. Incorporating CR in concrete makes concrete sustainable and reduces the consumption of natural aggregates [3]. Asphalt rubber (AR) mixtures have been created using the wet, dry, and blend methods, which are the three basic methods of adding CR. The results showed that expanding the use of the enhanced dry method, which utilizes fine crumb rubber greater than 0.6 mm as a substitution of aggregate since it balances the simplicity of utilization and the accomplished performance. The manufacture and application of bitumen emulsions enhanced with CR are intended to produce a superior emulsion for paving techniques with minimal negative environmental effects. AR mixtures improve the resistance of pavement. Enhancement technology of paving agrees with environmental requirements [4]. The effectiveness of crumb rubber concrete created in a 1.4 T magnetic field with great amounts of heat-treated rubber particles and magnetized water (MW) was examined. CRC included heat-treated rubber that had been exposed to 200 °C for two hours and 100% magnetized water for 24 hours showing good results. When utilizing a rubber ratio of 40%, these conditions led to a 74% increase in compressive strength recovery and improvements in impact resistance about 2.2 times at first fracture and 92% at final failure. The microstructural examinations revealed that pre-treatment of rubber with heat reduced the zinc content in rubber particles from 8.32% to 1.89%, formed a strong outer coating for the rubber, and burned-out undesirable materials in rubber particles, all of which improved compressive strength and impact resistance of crumb rubber concrete [5]. The modified-asphalt-rubber (MAR) mixtures were created by various dosages. The physiochemical characteristics of MAR were shown to be significantly influenced by the kind of additives and quantity of each material, according to the material examination technologies such as infrared spectroscopy and X-ray. When compared to traditional asphalt rubber, it comprises crumb rubber between 15 - 20% of the asphalt binder's weight., this study highlighted the optimum utilization of CR originating out of tires in applications for paving by incorporation of greater volumes larger than 62% in the creation of MAR. When the fatigue behavior of the traditional mix and MAR-modified combined with natural aggregates were examined, it became clear that the MAR-modified would have a greater fatigue life by more than twice and higher durability [6]. asphalt with crumb rubber was prepared by the shear process of high speed. Fundamental and rheological characteristics of asphalt were enhanced as the ratio of crumb rubber raised. Nevertheless, using asphalt with high-ratio crumb rubber causes high viscosity and poor stability as well as preventing the mixture from being compacted and decreasing its water stability [7]. When compared to natural fine aggregate, crumb rubber is distinguished by having a low specific gravity, is hydrophobic, and traps air, which reduces its workability and causes it to perform poorly when bonding with cement mortar. Reduction in the compressive strength, indirect tensile strength, modulus of elasticity, and failure behavior of crumb rubber concrete at different rubber ratios because of poorly performing interface transition zone and the distribution of crumb rubber particles is irregular [8]. Fine aggregate was partially substituted volumetrically of a ratio up to 50% with long crumb rubber primarily less than 4.76 mm. Cylindrical samples with varying amounts of crumb rubber have been set up and put through the axial compressive load. Additionally, control samples are developed and put through testing. The compressive strength and modulus of elasticity of the samples were determined. The findings indicated that the crumb rubber reduced the value of concrete's compressive strength and modulus of elasticity [9]. Fine aggregates were partially replaced with rubber crumbs. Rubberized Portland cement concrete's long-term material properties were assessed. At the age of five years, compressive, indirect tensile strength, and elastic modulus were determined. Non-destructive tests were used to evaluate the coefficient of the material. The density of CR concrete reduces with increasing a substitution ratio of sand by crumb rubber. For specimens made of CR concrete, density decreased after 5 years. As the crumb rubber ratio rises, the elastic modulus declines [10]. Different ratios of crumb rubber particles (5, 10, 15, 20, 25, and 30%) were incorporated into the mixture as a partial substitution of the gravel by volume. According to the results, adding crumb rubber to roller-compacted concrete pavement mixes alters their behavior. The roller-compacted concrete pavement had more ductility with crumb rubber. the disadvantage of CR was the reduction in mechanical characteristics of roller-compacted concrete pavement. The crumb rubber particles were treated, and the mixture was supplemented with silica fume. to solve the problem. The outcomes demonstrated that by altering the surface roughness of rubber particles, the behavior of roller-compacted concrete pavement can be enhanced [11]. The ductility of CR concrete including burnt clay brick powder was studied. Three beams were examined in the flexure test whereas the other three failed in both the shear and flexure tests. Ductility enhanced in beams including 5% burnt clay brick powder and 10% CR by 23.47% compared to that of reference beams. This improvement in ductility is accompanied by a 15.31% decrease in bending load. The beam with 5% burnt clay brick powder and 10% CR that failed in the shear and flexure test had 14.59% more ductility and 16.33% less load than the reference beam [12]. The rubber is heated at 200 °C before being put into concrete. Clearing the surface of various impurities that are present and producing a hard surface of the crumb rubber improves the interface and stress transmission between rubber and concrete. Treated crumb rubber with heat has a great bond. the results indicated positive improvements in concrete properties. Treated crumb rubber with a size #40 mesh and 20% of crumb rubber ratio increased the compressive strength by 60.3% [13].

2. Research Significance

Much of the previous research used rubber waste as a partial replacement for aggregates to reduce its undesirable impact on the environment, and these results provided low compressive strength. The current research aims to improve the compressive strength of crumb rubber concrete (CRC) by partial replacement of total aggregates with treated crumb rubber, by two methods of treatment, water, and benzene. The research also studies the effect of the treatment of rubber on the other mechanical properties of concrete such as flexural strength and indirect tensile strength. To determine the performance of CRC the following tests were carried out, water absorption, modulus of elasticity, and density. The results of this study lead to the use of CRC in paving road applications, playgrounds, and machine bases.

3. Experimental Program

The various materials utilized in this research were ordinary Portland cement (42.5N type I). Natural sand with

4.75 mm in size, fineness modulus of 2.65, bulk density of 1790 kg/m3, and specific gravity of 2.56. Dolomite with 19 mm in size, bulk density of 1660 kg/m3, and specific gravity of 2.63. Crumb rubber particles are demonstrated in Figure 1. were used as a partial replacement of sand passing from sieve No. 3/16 and reserved on sieve N0. 7 and as a partial replacement of dolomite passing from sieve No. 3/8 and reserved on sieve N0. 3/16 with a bulk density of 530 kg/m3, a specific gravity of 0.97, and content of rubber hydrocarbon of 45%.

Figure 1. Crumb rubber particles

4. Concrete Mixes

This experimental work investigated how the quality of concrete was modified when CR was used in place of some of the aggregates. Total aggregates were substituted with CR particles at ratios of 0, 2.5%, 5%, 7.5%, and 10% by volume. CR particles were treated by two methods, the first method is soaking in water for a full day and the next step was drying in the air to make CR behave as hydrophilic. This improves the bond between treated CR and cement mortar, minimizing cavities within the concrete and enhancing its compressive strength. The second method is treating by placing CR particles in benzene for half an hour, then washing it with water and leaving it to dry. This is because tires during their manufacturing contain zinc salts. These salts reduce the adhesion of CR to cement and cause the appearance of a layer of zinc on the concrete surface after 5-7 days of pouring concrete which then turns into a fine powder when exposed to the sun. The zinc salts are insoluble in water, while they are soluble in hot benzene, where they are neutralized in benzene and make the surface of CR rougher, which leads to increased adhesion of the mortar and the surface of rubber crumbs. Table **1** shows the components of the concrete mix which were designed with the British method and the experimental mixture was used in the laboratory. The weight of crumb rubber was obtained by partial replacement of total aggregates at ratios of 2.5%, 5%, 7.5%, and 10% by volume. 2.5% of total aggregates (T.A) were replaced in mix M1 with crumb rubber which 5% of fine aggregates (F.A) were replaced with fine crumb rubber (FCR) and 95% of course aggregates (C.A) were replaced with course crumb rubber (CCR). considering the bulk density of sand, dolomite, and crumb rubber when calculating the weight of crumb rubber and so for other mixes.

Table 1. The components of concrete mix (Kg/m^3)

Mix	Water: Cement =50%				CCR	FCR
	W	C	C.A	F.A		
Control	175	350	1240	620	0	0
M1 2.5%T.A= 5%F.A+95%C.A	175	350	1195.8	617.7	14.1	0.7
M2 5%T.A= 10%F.A+90%C.A	175	350	1156.3	610.7	26.7	2.75
M3 7.5%T.A= 20%F.A+80%C.A	175	350	1128.4	592	35.6	8.26
M4 10%T.A= 25%F.A+75%C.A	175	350	1100.5	573.5	44.5	13.8

5. Results and Discussion

5.1. Slump of Fresh Concrete

The slump test of fresh concrete was performed to investigate the influence of the addition of CR particles to the mixes on its workability. The slump test for fresh concrete is conducted in compliance with ASTM C143. The slump values are shown in Figure (2). It was observed that the slump of CR concrete mixes decreases compared to that of the reference mix. This can be explained that crumb rubber is distinguished by having a low specific gravity, is hydrophobic, and traps air which reduces its workability [8]. There was a slight difference in slump values in the case of treating CR particles with water and treating with benzene as benzene treatment is used only to enhance the adhesion of cement mortar and the surface of CR particles.

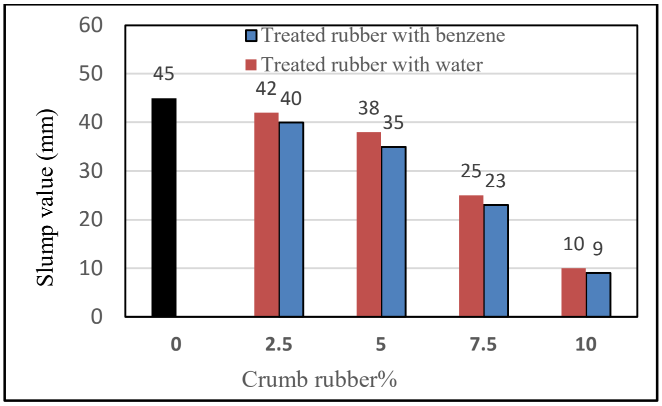

Figure 2. The slump of fresh concrete for all mixes

5.2. Compressive Strength Test

Concrete cubes of 15×15×15 cm were utilized with CR particles and tested by compression machine after 7 and 28 days of curing [14]. Figures 3 and 4 illustrate the influence of CR particles on compressive strength. The compressive strength decreased in the case of adding CR as a partial substitute for the total aggregates compared to that of the reference mix in the case of treating CR particles with water and benzene at 7 and 28 days of curing because of weak interface transition zone behavior of CR and distribution of CR particles is irregular [8]. The compressive strength decreased by 20%, 31.67%, 43.33%, and 53.33% than that of the reference mix at 28 days of curing in the case of water treatment, while it decreased by 10%, 16.67%, 33.33%, and 40% in the case of benzene treatment at the ratios of CR 2.5%, 5%, 7.5%, and 10%, respectively. Thus, this concrete can be used at a rubber content of 2.5% of total aggregates and treated in benzene in paving highways. The compressive strength improved in the case of treating CR particles with benzene than treating them in water as shown in Figure 5, where the treatment of CR particles with benzene makes their surface rough, because benzene removes zinc salts in rubber [1,15] which increases the adhesion of cement mortar and surface of CR particles, and thus improves the compressive strength of concrete. While in the case of treatment CR with water there is weak bonding between CR particles and cement past [16,17]. Also, this can be explained that there are air bubbles in the rubber due to its behavior as it is hydrophobic whereas soaking CR in water decreases these air bubbles [1,18].

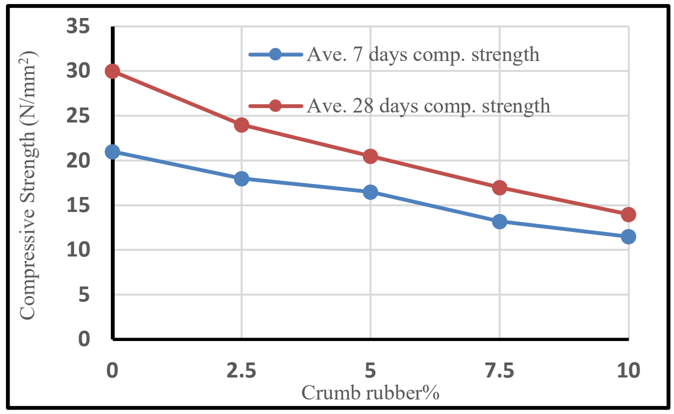

Figure 3. The influence of water treatment of CR particles on the compressive strength of all mixes

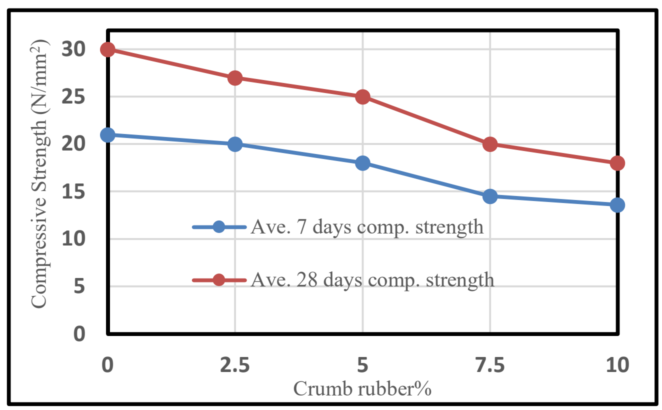

Figure 4. The influence of benzene treatment of CR particles on the compressive strength for all mixes

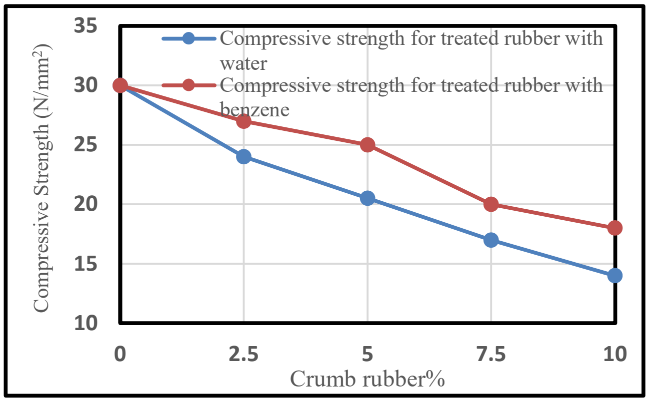

Figure 5. Comparison between compressive strength of treated CR particles with water and benzene for different mixes and reference mix at 28 days of curing

5.3. Flexural Strength Test

The concrete beams with dimensions of 10×10×50 cm were used in the flexural strength test. They were tested after 7 and 28 days of curing [19, 20]. The results of flexural strength are represented in Figures 6 and 7. It took the same trend of compressive strength. The flexural strength values for mixes containing CR particles and treated with water and benzene reduced compared to the control mix at the age of 7 and 28 days. The values of flexural strength for CR mixes treated with benzene increased than CR mixes treated with water as illustrated in Figure 8 because treating CR particles with benzene improved the adhesion between cement mortar and the surface of CR particles [1]. The increase in CR content reduced the flexural strength of mixes by 20.9%, 32.56%, 53.5%, and 50% than that of the reference mix at 28 days of curing in the case of treating CR particles with water, while it reduced by 11.6%, 20.9%, 34.9% and 44.18% in case of treating CR particles with benzene at ratios of CR 2.5%, 5%, 7.5%, and 10%, respectively.

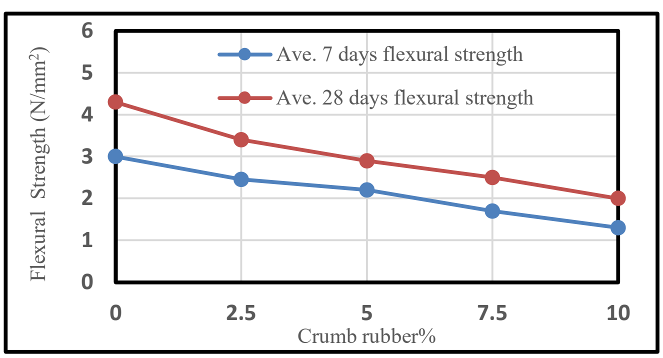

Figure 6. The influence of water treatment of CR particles on the flexural strength of all mixes

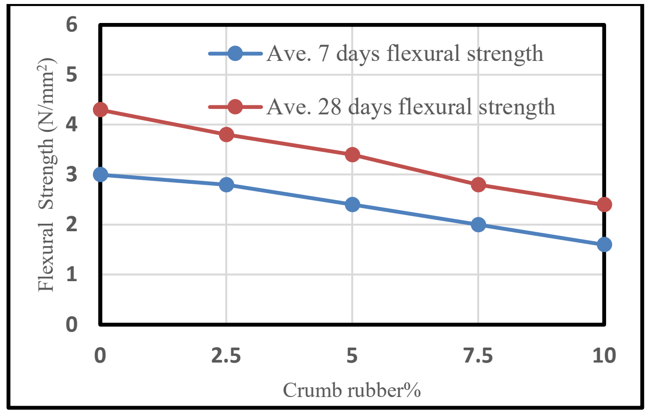

Figure 7. The influence of benzene treatment of CR particles on the flexural strength of all mixes

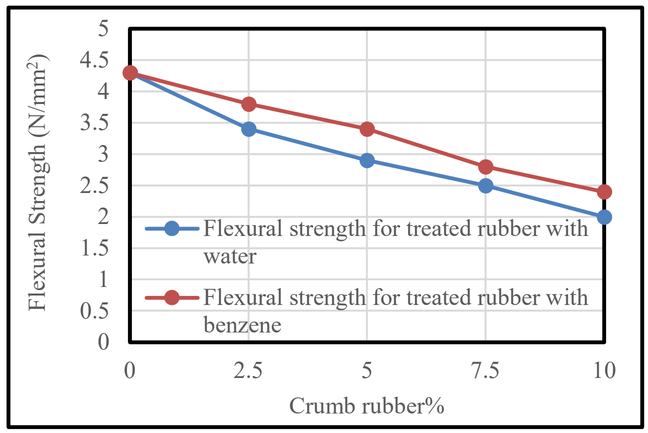

Figure 8. Comparison between flexural strength of treated CR particles with water and benzene for different mixes and reference mix at 28 days of curing

5.4. Splitting Tensile Strength Test

The cylindrical specimens used in the indirect tensile strength have dimensions of 15 × 30 cm. They were tested after 7 and 28 days of curing in a compression machine [21]. The splitting tensile strength findings are demonstrated in Figures 9 and 10. It was noticed that the indirect tensile strength for mixes containing CR particles and treated with water and benzene decreased compared to that for the reference mix at 7 and 28 days of curing. The higher the CR ratio, the lower the indirect tensile strength for mixes. The indirect tensile strength of CR mixtures treated with benzene had higher indirect tensile strength values than CR mixtures treated with water as illustrated in Figure 11. The indirect tensile strength reduced by 16%, 28%, 40%, and 48% than that of the reference mix at 28 days of curing in the case of water treatment, while it reduced by 8%, 16%, 28%, and 36% in the case of benzene treatment at the ratios of crumbs rubber 2.5%, 5%, 7.5%, and 10%, respectively, because of poorly performing interface transition zone [8].

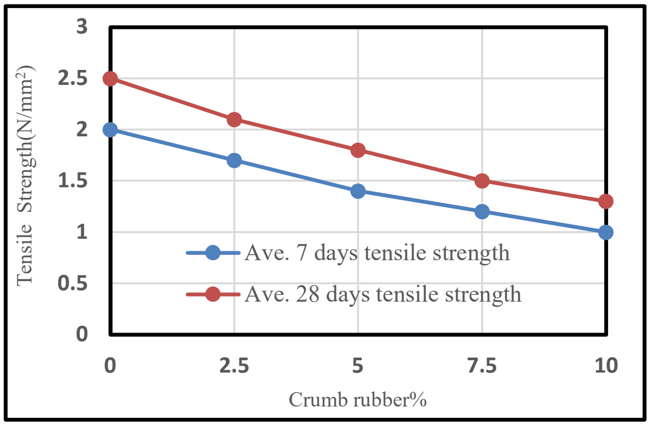

Figure 9. The influence of water treatment of CR particles on the indirect tensile strength for all mixes

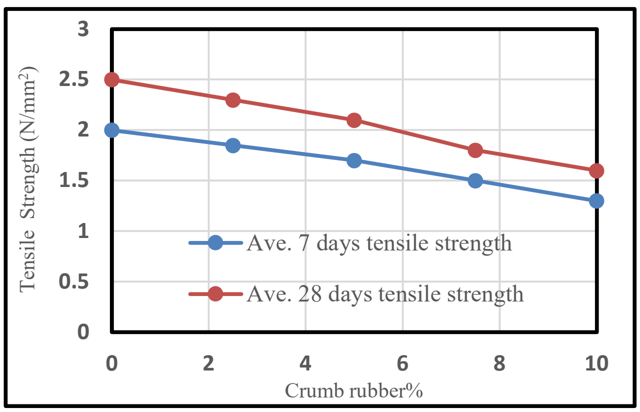

Figure 10. The influence of benzene treatment of CR particles on the indirect tensile strength for all mixes

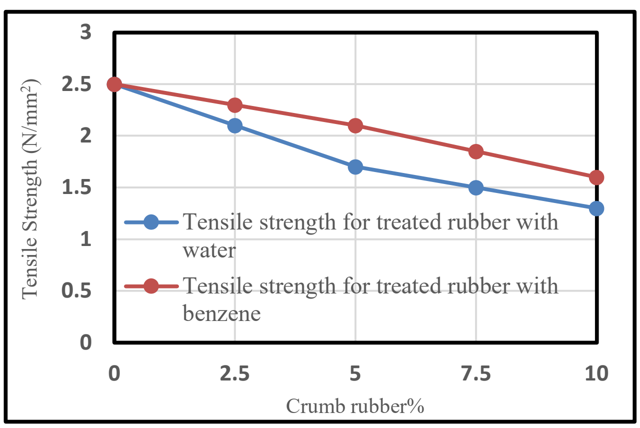

Figure 11. Comparison between the indirect tensile strength of treated CR particles with water and benzene and reference mix for all mixes at 28 days of curing

5.5. Water Absorption Test

Concrete cubes with dimensions of 10×10×10 cm were tested to determine the water absorption rate after 28 days of curing [22]. Figure 12 illustrates the influence of crumb rubber treated with water and benzene on the water absorption of mixes. It was noticed that the water absorption of CR mixtures treated with water and benzene increased compared to that of the reference mix at 28 days of curing because of the increase in the air voids as the percentage of CR increases [3, 23, 24]. The water absorption rate of mixes with CR treated with benzene decreased than that of CR mixtures treated with water because of the great adhesion of cement mortar and the surface of CR particles as a result of the roughness of the rubber surface treated with benzene [1]. The least rate of water absorption of CR mixes was attained by the mixture that had 2.5% CR as a partial substitution of total aggregates.

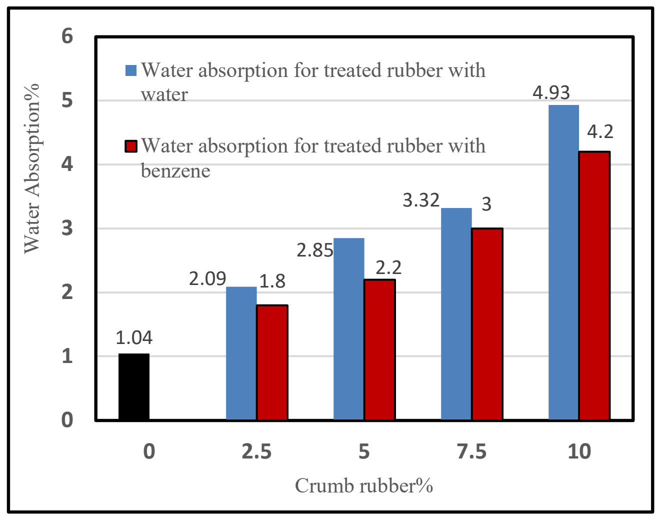

Figure 12. Comparison between the rate of water absorption of treated CR particles with water and benzene for all mixes and reference mix at 28 days of curing.

5.6. Density Test

concrete cubes with dimensions of 15×15×15 cm were tested to measure the density of samples after 28 days of curing [25]. CR mixes density in the case of treated CR with water and benzene at 28 days of curing decreased in comparison to that of the reference mix as illustrated in Figure 13. When the CR particles ratio was increased as a partial substitution for total aggregates, the density of the mixtures decreased. The main reason for this decrease is CR particles have a lower density than aggregates and entrapped air between CR particles and cement paste [3].

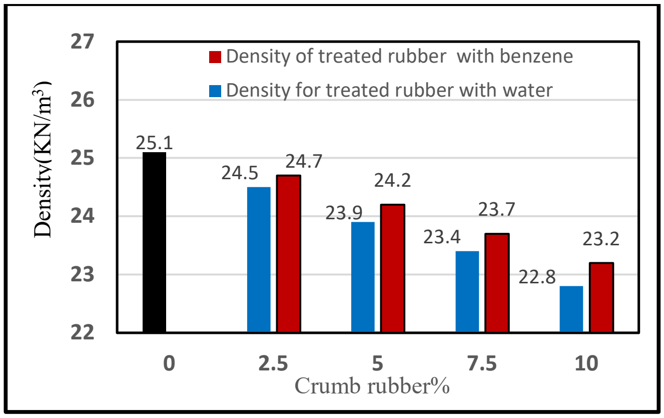

Figure 13. Comparison density of treated CR particles with water and benzene for all mixes and reference mix at 28 days of curing

5.7. Elastic Modulus

The elastic modulus test determines the stiffness of concrete mixes according to ASTM C-469. The outcomes of the elastic modulus are shown in Figure 14. It was noticed that the elastic modulus of CR mixes treated with water and benzene reduced compared to that of the reference mix. Also, it reduced with an increasing ratio of CR particles compared to the reference mix. It reduced by 17.85%, 32.14%, 44.6%, and 57.1% than that of the reference mix in the case of water treatment, while it reduced by 10.7%, 21.4%, 33.9%, and 42.85% in the case of benzene treatment at the ratios of crumbs rubber 2.5%, 5%, 7.5%, and 10%, respectively. The reason for this reduction is the weak bond between cement paste and the surface of CR particles [8,10]. And therefore, concrete's brittle properties are improved, becoming more ductile. This makes CR concrete suitable for use in pavement, playgrounds, and machine bases [1].

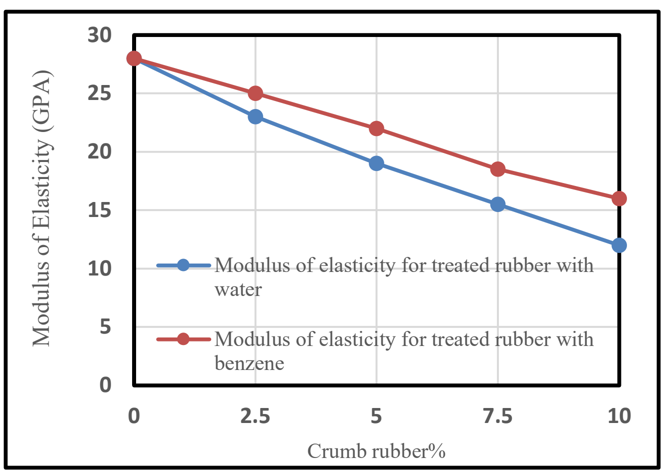

Figure 14. Comparison of elastic modulus of treated CR particles with water and benzene for all mixes and reference mix

6. Conclusions

It can be deduced based on the evaluation and discussion of the experimental results that:

1- The utilization of crumb rubber particles as a partial substitution for total aggregates has negative effects on the mechanical properties of concrete. The treated CR with benzene limits these negative effects to safe levels.
2- The workability of CR mixes reduced as the amount of crumb rubber elevated compared to the reference mix.
3- The water absorption rate elevated with a rising ratio of crumb rubber compared to that of the reference mix.
4- The density of CR mixes reduced as the amount of CR rose compared to that of the reference mix.
5- The elastic modulus decreased with an increasing ratio of CR particles in comparison to the reference mix.
6- The mixture contained 2.5% crumb rubber of total aggregates and treated with benzene was considered the best mixture containing rubber as it had a little reduction in strength of compressive, modulus of rupture, and indirect tensile with comparison to the reference mix.

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