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Treated Waste Tire Using Cement Coating as Coarse Aggregate in the Production of Sustainable Green Concrete

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Abstract: Waste tire rubber is one of the most concerning environmental pollution issues. With the increasing demand for automobile production, the rate of waste tire generation has also increased. However, these tires often end up stockpiled and not properly disposed of. This non-biodegradable waste poses severe fire, environmental, and health risks. Due to the progressively severe environmental problems caused by the disposal of waste tires, the feasibility of using such elastic waste materials as an alternative to natural aggregates has become a research topic. The main objective of this research is to investigate the changes in the mechanical and durability properties of concrete with the inclusion of waste tire rubber at specific contents. A total of 80 cylinders measuring 100 mm × 200 mm were cast with waste tire aggregate as a partial replacement for natural coarse aggregate (5% and 10% by weight of natural coarse aggregate). A surface treatment of tire aggregate using a cement coating was performed to study its effect on concrete properties. This research indicates a noticeable reduction in the compressive and split tensile strength of concrete containing untreated waste tire rubber compared to normal concrete made with natural aggregates. However, an improvement was observed when the surface of tire aggregates was coated with cement grout. Additionally, it was noted that the slump value, water absorption, and porosity increased as the percentage of rubber increased. Nevertheless, unlike normal concrete, the failure pattern in tire-mixed concrete occurs gently and uniformly, indicating ductile behavior.

Keywords: waste tire aggregates; recycling; rubberized concrete; surface treatment; mechanical strength and durability properties

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1. Introduction

The contributions of gravel and sand to the construction industry are well known for their uses in concrete production. However, the supply and scarcity of sand and gravel at reasonable rates are currently a concern for the construction sector. Natural aggregates are generally extracted from natural sources, leading to significant environmental problems brought on by deforestation and the collection of natural aggregates from river bottoms, lakes, and other water bodies, as well as the crushing of quarry rock and larger boulders. This scenario has drawn the concern of relevant authorities. Therefore, many countries are setting restrictions on extracting natural aggregates and their crushing to conserve natural resources [1].

One way to mitigate this problem is to find substitutes for conventional natural aggregates that can be used in concrete and have similar properties [2,3]. Green construction is being adopted in the construction industry to limit risks to human health and the environment, decrease pollution, and enhance sustainability. Hence, green concrete has become important in the construction industry in the last few decades. Utilizing waste products to produce new concrete and properly disposing of waste materials benefits the environment and the economy.

Scrap tires are considered hazardous waste, and if managed inappropriately, they can harm the environment. Uncovered waste tires may serve as nesting places for disease-spreading insects. Waste rubber tire stacks are flammable and easy to ignite, resulting in thick smoke and harmful runoff into nearby areas [4]. Numerous waste products have been proposed as acceptable or even advantageous additives to concrete. These include silica fume, bottom ash, fly ash, wood, and cellulose. Rubber from old tires is one of the most recent waste materials to be studied for its possible application in the building sector [5,6]. Due to the environmental harm waste tires can cause, recent years have seen attention focused on proper disposal methods.

When scrap tires are incorporated into concrete, the resulting material gains numerous benefits, and its properties are altered [7]. For example, rubberized concrete can improve the ductility of cement-based concrete, which is typically brittle. Additionally, rubberized concrete may be beneficial when subjected to dynamic loading from moving cars or pedestrians using sidewalks [8]. Furthermore, waste rubber from tires can be used in larger quantities for fuel, pigment soot, bituminous pastes, roof and floor coverings, and in the paving sector [9–11]. Waste rubber aggregates can be categorized into four types: (i) chipped, (ii) crumb, (iii) granular, and (iv) fibers, depending on the rubber dimension, shape, and the substance being replaced [12].

Previous research has shown an increase in the slump value with an increasing percentage of waste tire aggregates [13]. However, when waste tires are used as fine aggregate replacements exceeding 10%, the workability of concrete is significantly impacted, and the concrete becomes nearly unworkable when mixed with 30% rubber [14]. Research findings from several authors have shown that regardless of the tire particle size, rubber substitution stage, or substituted kind of combination, a reduction in the compressive strength of rubberized concrete is unavoidable when certain types of tire aggregate are used as a partial replacement in the mixture [15–17]. Additionally, the lower value of the modulus of elasticity (E-mod) of tire-mixed concrete compared to natural aggregate concrete, low adhesion and bond energy, and more air trapped between tire particles and cement paste are all contributing factors to this drop [18]. The lower stiffness of tire aggregates in contact with the higher stiffness of natural aggregates can develop a stress zone at the contact surface and lead to the formation of cracks [19]. This could ultimately govern the mechanical strength behavior of concrete. The adhesion between tire aggregate and cement particles, or the interfacial transition zone (ITZ), needs to be improved to reduce the amount of strength reduction.

Hence, several authors have applied different types of surface treatment to tires to improve their ITZ with cement matrices [20–22]. Some surface treatments applied to tire aggregates were sodium hydroxide (NaOH), silane coupling agent (SCA), and solvents such as ethanol and acetone, as well as silica fume [20–22]. One study showed that flexural and splitting strengths were increased when the pretreatment was applied to the tire surface [23]. Another study in which the rubber aggregate was pretreated with a NaOH solution or SCA before use in concrete showed higher compressive and flexural strengths than the untreated one [24]. In another study, five different surface treatments on rubber surfaces were tested, and it was concluded that all of the treatment processes improved strength, by 27% to 56%. However, sulfuric acid and silica fume showed the most noticeable development of a denser ITZ among all five methods [25]. The study also concluded that the NaOH solution produced the best result of the surface modifications in increasing the rubber's hydrophilic nature [26]. Tire surfaces can also be treated with chemicals such as acetone, which has been demonstrated to increase mechanical strength compared to untreated rubber [27]. Rubberized concrete subjected to calcium hypochlorite $Ca(ClO)_2$ for 72 h had a strength comparable to reference concrete [28].

Similarly, the tensile strength of the concrete also showed a similar trend of strength improvement when tire aggregates were treated with the different solvents discussed here [28]. The researchers also used tire aggregate in powder form [29,30] to replace the natural fine aggregate in concrete. Like coarse tire aggregate, concrete strengths were also reduced as the percentages of tire powder content increased in the mixes.

Research effort is on the rise regarding the use of waste tires in concrete in various forms to replace coarse and fine aggregates. However, the applications of this concrete are scattered and limited in laboratory investigations. There are as yet no guidelines for using tire aggregate concrete. Currently, random tests are reported by researchers using different percentages and forms of tires in concrete. Additionally, there is a lack of proven technologies and methods for processing the tire aggregates so that they can be used in concrete without any detrimental effect.

In this study, the surface of tire aggregates was treated with cement grout as a more environmentally friendly and cost-effective alternative to the chemical-based treatments used in previous research. The experiment involved replacing natural coarse aggregate with 5% and 10% (by weight) waste tire aggregate in concrete, both untreated and treated with cement grout. The workability of fresh concrete, the compressive and split tensile strength of hardened concrete, and the water absorption and pore volume in the different concrete mixes were all measured. Microstructural analysis was also conducted to validate the experimental results.

2. Materials and Methods

2.1. Materials

The material compositions for different concrete mixes are shown in Table 1. REF represents the reference concrete mix, whereas R5 and R10 refer to the mixes with 5% and 10% untreated tire aggregate as percent replacements of natural coarse aggregates by weight. Similarly, R5-T and R10-T represent concrete mixes cast with 5% and 10% treated tire aggregate. CEM II 42.5 N cement (i.e., cement with additives like fly ash and slag and 28-days strength over 30 MPa) was used as the main binder [31]. Natural stone chips as coarse aggregate with a maximum size of 19 mm were used. In addition, sand with a fineness modulus (FM) of 2.58, classified as medium-fine aggregate, was used as fine aggregate. Figure 1a shows the sieve analysis for all aggregates (both fine and coarse) used in this study. The FM values of stone chips and tire aggregates were 7.74 and 7.47.

Table 1. Concrete mix design used in this study.

Mixture	% TA	w/c Ratio	Water (kg/m^3)	Cement (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	TA (kg/m^3)
REF	0	0.50	196.3	393	808.3	1036.2	0
R5	5	0.50	191.3	383	778.7	959.3	50.5
R10	10	0.50	186.5	373	768.2	886.3	98.5

Note: FA, CA, and TA are defined as fine aggregate, coarse aggregate, and tire aggregate.

The tire aggregate is shown in Figure 2, converted from waste tires, which were collected from a local tire company. A tire-cutting machine was used to obtain the desired shapes, with particle sizes ranging from a minimum of 5 mm to a maximum of 19 mm. It was collected and cleaned with water to remove impurities, harmful materials, and dust, then dried at ambient temperature. Clean potable water was used in the concrete mixes. Treatment was carried out by coating the chopped tire aggregate surfaces with cement grout, wherein the cement and water content was 1:2 (cement:water). All tire aggregate was sunk into the cement grout for about 5 min to ensure the surfaces were adequately coated before drying at ambient temperature for a minimum of 48 h, as shown in Figure 2b. It should be noted that the total amount of cement for the grouting was not adjusted for use in the concrete mixes containing cement-coated tire aggregate (as shown in Table 1).

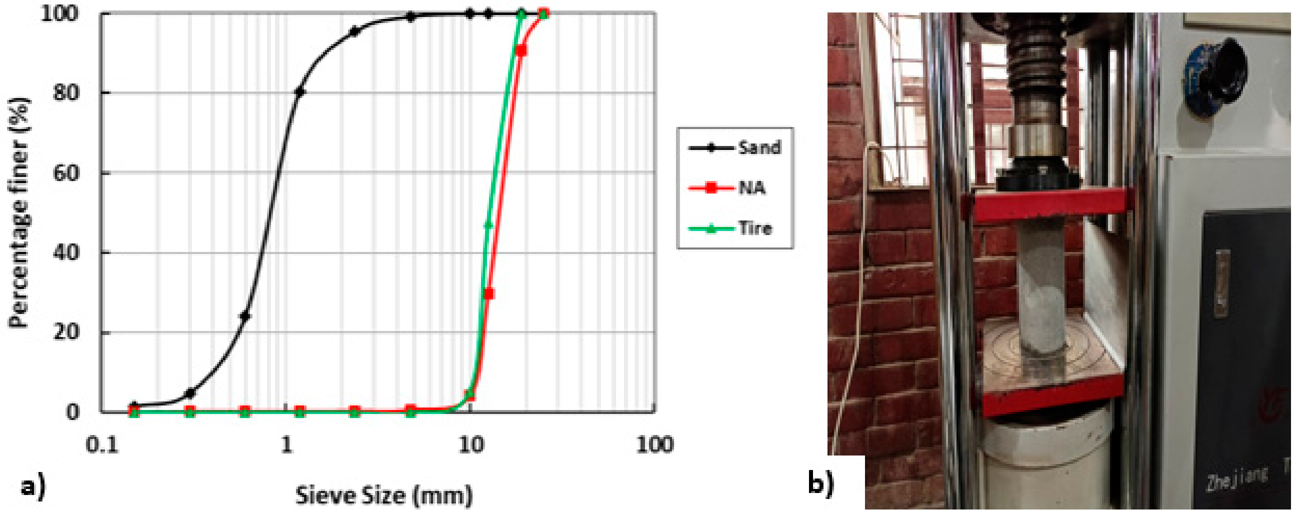

Figure 1. (**a**) Sieve analysis of sand, coarse natural aggregate (NA), and tire aggregate and (**b**) UTM machine used for the mechanical test.

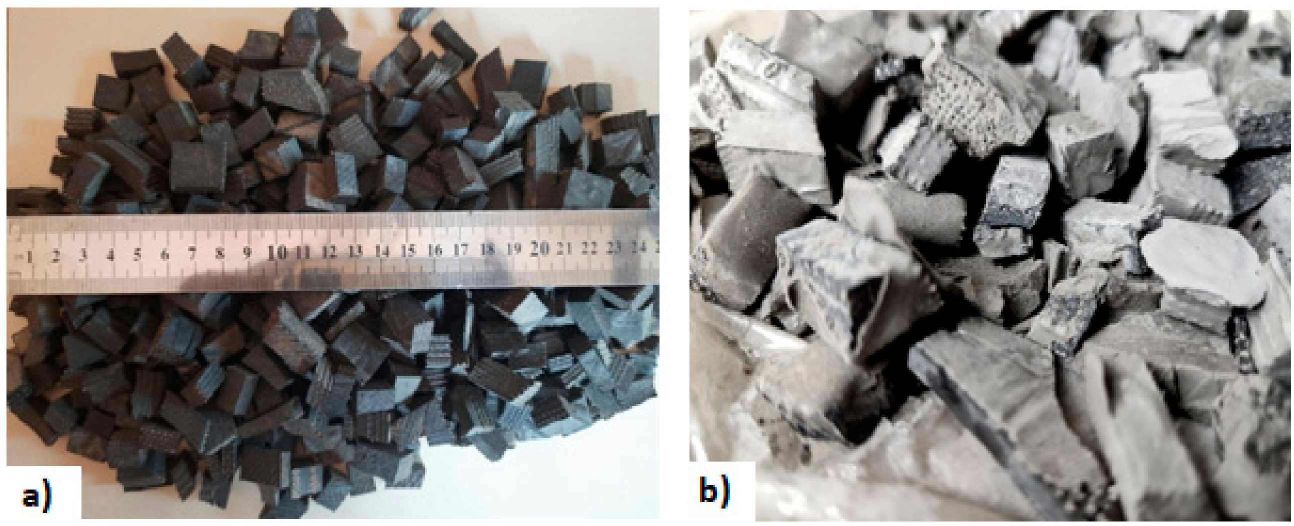

Figure 2. Waste tire aggregates, (**a**) untreated and (**b**) treated.

2.2. Sample Preparation and Testing

A slump test on the freshly mixed concrete was performed according to ASTM C143 [32]. In each batch of concrete mixes, 16 cylindrical samples (a total of 80 samples for five different mixes), each measuring 100 mm diameter by 200 mm length, were produced. After filling the steel molds with fresh concrete, the samples were kept at ambient temperature for 24 h before being placed into the water tank until testing. For the compression test, a minimum of three samples were tested for each curing age of 7, 14, and 28 days following ASTM C39 [33]. The remaining four samples were tested for split tensile strength according to ASTM C496 [34] after 28 days of water curing. A Universal Testing Machine (UTM) with a loading capacity of 3000 kN was used for these mechanical strength tests, as shown in Figure 1b. For the compressive strength test, the samples were placed under the compression plate vertically to apply a uniaxial compressive load at a loading rate of 4 kN/s. Furthermore, for the splitting tensile test, the sample was placed horizontally between two iron plates, one at the top and another at the bottom, to ensure the applied load was a line load. After placing the specimen, the load was applied until the sample failed, and the data were recorded.

The water absorption and permeable voids tests, also known as the pore volume test, were conducted according to ASTM C642-21, wherein 3 specimens were taken from each batch with a size of 100 mm diameter and 50 mm height, with a total volume of about 398 cm^3 [35]. For this test, water curing was continued for 28 days after casting the samples. Before testing, all the samples were taken out of the water and air dried for about 4 h before being placed inside the oven for 24 h, and the oven-dried mass was measured. After that, the oven-dried samples were again immersed in water for 48 h; the saturated surface dry (SSD) mass was recorded. Later, the specimen was boiled for 5 h, and another SSD weight after boiling was measured immediately after 14 h of cooling of the samples. Finally, the apparent mass of the samples was measured by immersing them in the water, as suggested in ASTM C642-21. The interfacial transition zone (ITZ) between the cement paste and aggregates was visualized using a scanning electron microscopy (SEM) machine. All SEM images were collected at the 10–15 kV mode of the microscope, and the whole area of images was between 1500 μm^2 and 3000 μm^2. A single factor analysis of variance (ANOVA) test was also performed to check for different concrete properties, and to determine whether, statistically, there was any significance when waste coarse tire aggregate (WCTA) was included in the concrete mixes.

3. Results and Discussion

3.1. Slump and Dry Density

The slump test result shown in Figure 3 reveals that the slump increased with an increment in the waste tire content. The maximum slump was recorded for concrete with 10% untreated tire aggregate, compared to other mixtures, as shown in Figure 3. This behavior is aligned with the literature, as many researchers revealed that rubberized concrete has better workability than normal concrete, as summarized in ref. [36]. For the 5% and 10% untreated tire aggregate concretes, the slump increased by about 12% and 20%, respectively, compared to the reference concrete. The dramatic increase of slump when cast with untreated tire aggregate could be associated with the lower absorption capacity of tire material (approximately 3.64%, reported in ref. [37]). Additionally, as shown in Figure 2a, the tire aggregate particles were less angular than crushed stone aggregate, i.e., tire aggregates are more rectangular and square. These properties may diminish the inter-particle resistance among the tire material and other constituents of concrete in the mix and leave the free water in the mix due to the significantly lower absorption of tire materials. In this manner, the tire aggregate can help the freshly mixed concrete to achieve a smooth flow (due to less energy required to overcome frictional stress in the matrix), resulting in a higher slump. Furthermore, typically, tire materials have a hydrophobic nature, i.e., they repel water and attract air bubbles on the tire surfaces, which may improve the quantity of air entrained in concrete mixes [38]. This behavior also helps to enhance the workability of concrete by keeping free water in the mix; with a significant amount of entrapped air, it can help improve the inter-particle movements and raise the slump value due to a better ball-bearing effect.

After the surface treatment by cement coating, the slump started to reduce compared to the same percentages of tire aggregate without surface treatment. For 5% and 10% treated tire aggregate in concrete, the slump increased by about 4.7% and 7.8% compared to the reference concrete. This might be due to the increased friction developed (i.e., better particle interlocking in the mix) in the rough surface of aggregate after treatment, thus hindering the particles' movement and reducing the slump. Furthermore, due to the coating, the tire aggregate surfaces changed from hydrophobicity to hydrophilicity, resulting in higher water absorption from the concrete matrix and a lessening of the slump. As the coated cement aggregates were dried, the propensity to absorb water became higher.

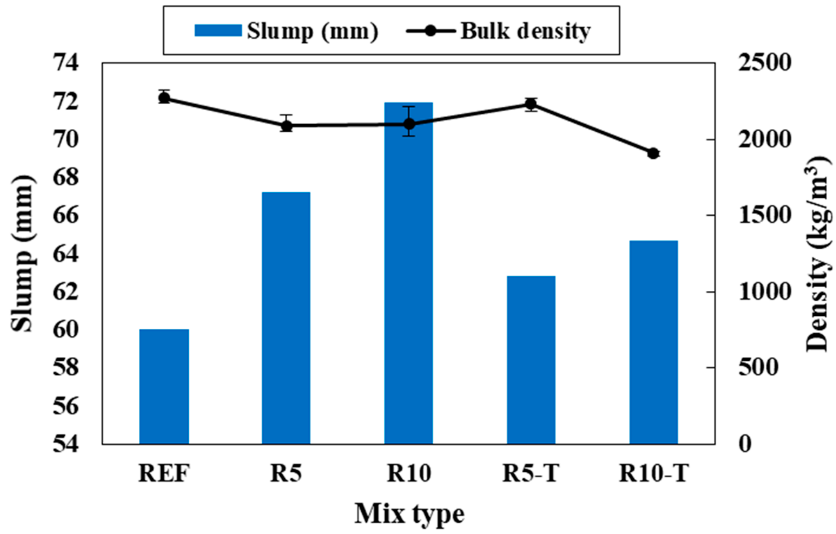

Figure 3. Slump value and bulk density of concrete mixes.

In addition, the specific gravity and density were significantly higher than untreated tire particles. The addition of cement grout for the treatment enhanced the density of freshly mixed concrete fabricated with treated tire aggregate compared with the untreated tire aggregate, which increased the interior hydraulic pressure caused by higher self-weight (see Figure 3) at the bottom of the slump cone. This behavior may decrease the movement of the aggregate and result in a lower slump in the concrete cast with treated tire aggregate than that cast with untreated tire aggregate.

The bulk density of different concrete mixes is also shown in the second Y-axis in Figure 3. The highest density was reported for the reference concrete, and the density reduced as the percentages of tire content increased in the mixes. This behavior is linked to the significantly lower specific gravity and density of tire aggregate (1.13 and 600 kg/m^3, respectively, as reported in ref. [37]) than the stone aggregate. Additionally, the incorporation of tire aggregate in the concrete mixes increased the incidence of air bubbles [38], thus increasing the porosity of concrete and decreasing its density. As reported earlier, the treated tire contained cement grout, which increased the density of the treated tire aggregate compared to untreated tire aggregate. This higher density of treated tire aggregate is likely to be the main reason behind the higher density of concrete fabricated with treated rather than untreated tire aggregate.

3.2. Compressive and Split Tensile Strength of Tire Concrete

The results of the compressive strength tests of tire concrete performance at different ages are shown in Figure 4. As anticipated, and as is consistent with other researchers' findings, the strength of concrete mixtures containing tire aggregate generally decreased. However, the strength gradually increased for each mix type along with the increments of curing duration. As shown in Figure 4, with 5% untreated tire aggregate replacement, at 7 days of curing, the compressive strength was reduced by 24.6% compared to the reference mixture, whereas with 10% untreated rubber aggregate, the reduction was 37.6%. At the same age, compared to the reference mix, the compressive strength reduction with treated tire aggregate (R5-T and R10-T) was 8.98% and 28.61%, respectively. At 14 days, compressive strength was lower than that of REF concrete for R5 and R10 by 20.29% and 43.90%, respectively, whereas concrete containing treated tire aggregate only decreased by 11.74% and 37.83% for R5-T and R10-T, respectively. Similarly, compared to the REF concrete, at 28 days of testing, compressive strength for R5 and R10 was 32.33% and 46.29% lower, respectively. Again, these reductions are smaller for treated tire aggregate concretes: 27.23% and 42.92% for R5-T and R10-T, respectively. Comparing the treated and untreated tire aggregate concretes, about 7.5% and 6.2% higher strengths of concrete were obtained for 5% and 10% inclusions of treated tire aggregate concrete than their counterparts.

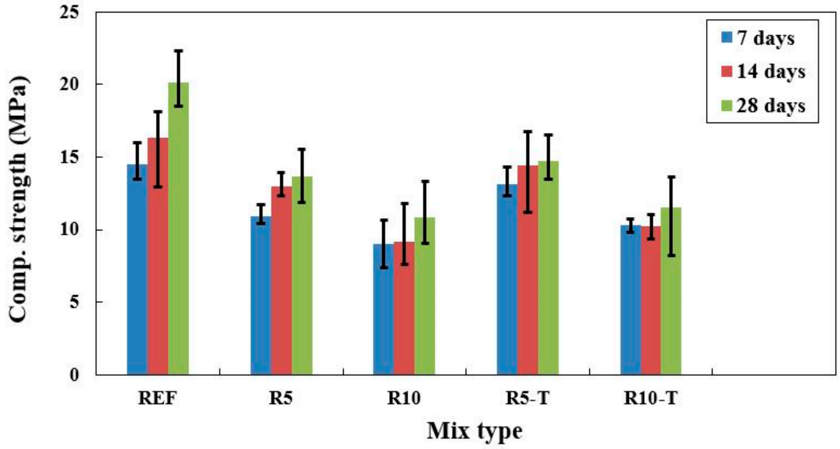

Figure 4. Compressive strength of all concrete mixes at 7, 14, and 28 days.

Figure 5 shows the splitting tensile strength results of all concrete mixes at 28 days. With a 5% replacement of coarse aggregate by tire aggregate, the splitting tensile strength was reduced by 12.6%, and was reduced by 31.92% when replaced with 10% rubber aggregate. Similarly, the tensile strength was reduced by 18.3% for 10% treated tire aggregate compared with the REF concrete. On the other hand, for R5-T concrete, the strength increased by 3% compared to the REF concrete. Overall, the samples with pretreated aggregate have shown less tensile strength reduction than untreated aggregate samples. For instance, with a 5% and 10% replacement of coarse aggregate by pretreated tire rubber aggregate, the tensile strength of the sample showed increases of 18.3% and 19.5% compared with untreated tire aggregate concrete.

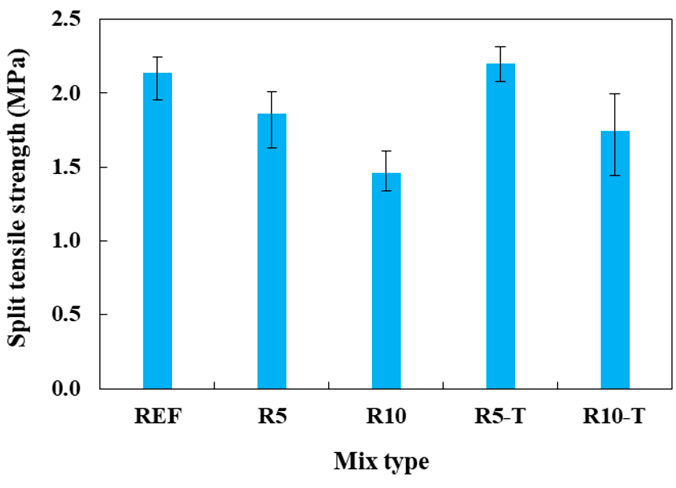

Figure 5. Split tensile strength of all concrete mixes at 28 days.

The reduction in strength could be explained by the smooth surface of tire aggregate or the weak ITZ formed between the tire aggregate surface and cement matrix. The hydrophobic nature of tire aggregate could also lead to a lower compressive and split tensile strength of tire concrete. Furthermore, tire aggregates have significantly lower strength and stiffness (i.e., lower modulus of elasticity [31]) compared to stone aggregates; thus causing an earlier and higher magnitude of deformation (i.e., more cracks near the ITZ) in tire aggregate concrete, offering significantly lower strength. Additionally, as shown in Figure 2a, the tire aggregates are less angular than crushed stone aggregates, which lessens the inter-particle resistance between the tire aggregates and other constituents of the concrete.

Along with the significantly lower specific gravity and density of tire aggregate and higher workability of tire concrete (as shown in Figure 3), tire aggregate can migrate effortlessly to the top portion of the specimens during compaction [31]. As a result, a remarkably higher concentration of tire aggregate occurred in the top portion of the specimens, revealing porous, permeable, and non-homogeneous concrete, thus lowering the strength of the concrete. In addition, tire aggregates in the concrete mix can dramatically increase air bubbles, resulting in higher porosity and permeability, leading to lower strength in the concrete. Nevertheless, with the surface treatment, the strength increased compared to the untreated samples, as a rough surface or hard layer around the tire aggregate was created, thereby enhancing adhesion between the tire aggregate and the cement matrix [38].

Furthermore, as the tire aggregate was coated with cement grout, the tire surfaces changed from hydrophobicity to hydrophilicity, thus dramatically enhancing the adhesion between the coated tire aggregate, cement mortar, and stone aggregate. This is aligned with the substantially inferior workability of concrete fabricated with treated tire aggregate than the untreated one, as shown in Figure 3. Therefore, this treated tire aggregate could boost the ITZ, limit the formation of air bubbles near the ITZ (i.e., lower porosity), and offer higher strength to the concrete. Indeed, the coating by cement increased the amount of cement in the mix more than the mix containing untreated tire aggregate, thus increasing the strength of the treated rubberized concrete. The experiments show that the strength reduces with the addition of untreated rubber aggregate but is enhanced using treated rubber aggregate. Additionally, a 5% pretreated tire replacement within all the mixes provided the most satisfactory value.

Different treatment methods of tire aggregate investigated by different researchers were also analyzed and compared with the experimental results, as shown in Figure 6 [23,31,39]. Strength ratio means the compressive strength ratio of treated tire aggregate concrete to untreated tire aggregate concrete with the same tire content. Analyzing the surface treatment results of some authors, it can be ascertained that the compressive strength increases for the treated tire aggregate concrete in a range of 6% to 25% in all cases compared to the concrete mix without the surface treatment of the tire material. From the results shown in Figure 6, it can be inferred that the cement-coated treatment method also produces the same range of strength improvement as the chemical treatment methods used in different studies. However, chemical treatment is more expensive and riskier to health than the simple cement coating method. Additionally, cement is more readily available in all regions than chemicals. Therefore, it is recommended that cement grout could be substituted for chemical treatments of tire aggregate without compromising the strength improvement of the concrete.

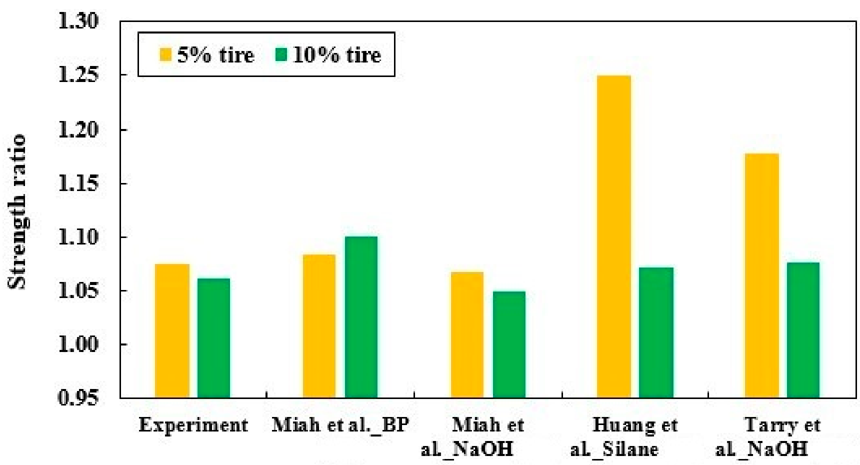

Figure 6. Compressive strength ratios calculated from treated and untreated tire aggregate concrete, reported by different researchers (note: BP means bleaching powder) [23,31,39].

3.3. Water Absorption and Pores in Tire Concrete

According to the test results shown in Figure 7, the percentages of pore volume and absorption increase when coarse aggregate is replaced by waste tire rubber aggregate. This could be due to a weak adhesion between tire aggregate and cement paste, which may form a capillary zone that helps in water penetration [39]. However, a slight improvement in pore volume was noticed with the surface treatment of tire aggregate. This might be because of the pore-blocking effect of the surface treatment, which was previously analyzed using back-scattered image analysis and electrochemical impedance spectroscopy [40]. For the 5% untreated tire aggregate replacement, about a 7% higher pore volume was found in the concrete compared to the REF concrete, as shown in Figure 7a. This value was only about 2.8% for treated tire aggregates for the same replacement level. Interestingly, for 10% tire aggregates, pore volume and absorption for treated and untreated aggregates were lower than for 5% tire aggregates in the concrete. The treatment seems not to show any noticeable improvement in the absorption values of concrete, as shown in Figure 7b.

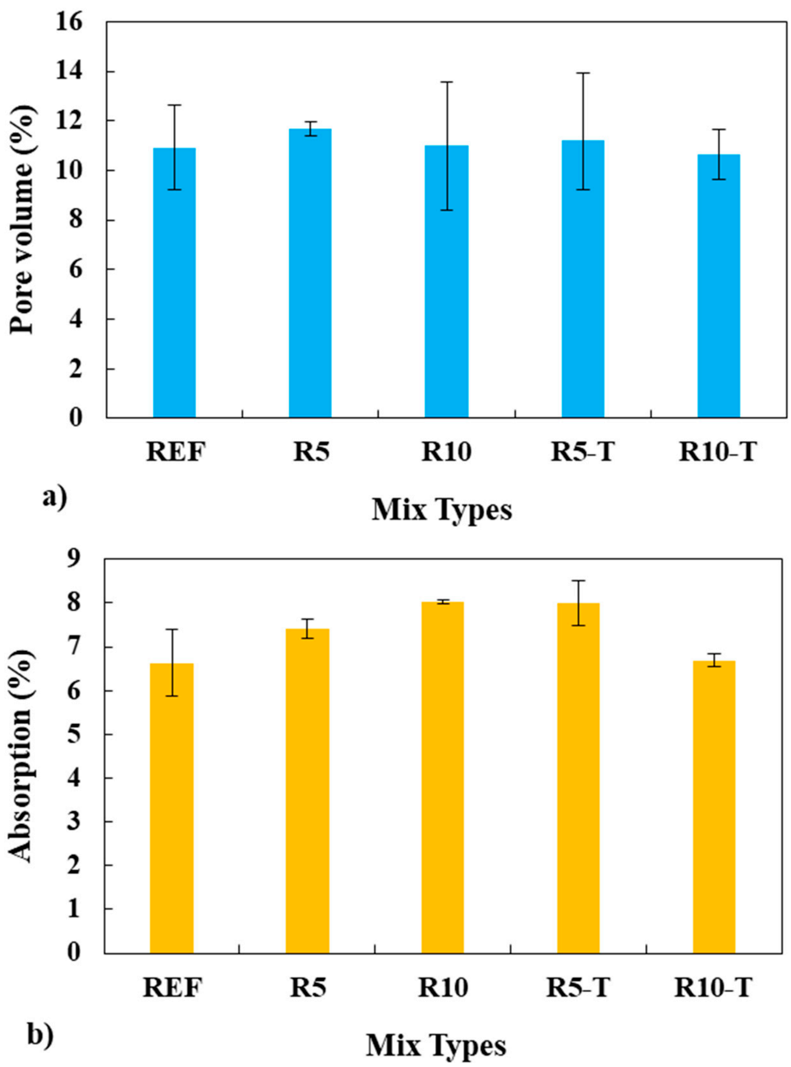

Figure 7. Percentages of (**a**) pore volume and (**b**) water absorption of all concrete mixes at 28 days.

3.4. Relationship of Compressive Strength to Other Properties

Figure 8 shows the variation in compressive strength with respect to slump and bulk density. Polynomial relationships were found among compressive strength, slumping, and densities. As the slump decreased, the compressive strength of the concrete increased. Similarly, as the density increased, concrete strength also increased. Similarly, water absorption and concrete pores were also related to compressive strength, as illustrated in Figure 9. However, no strong relationships were noticed between these parameters. It is also worth mentioning that these relationships exist regardless of the treatment and percentages of tire aggregate. These relationships typically help to predict the concrete behavior when at least one of the properties is known.

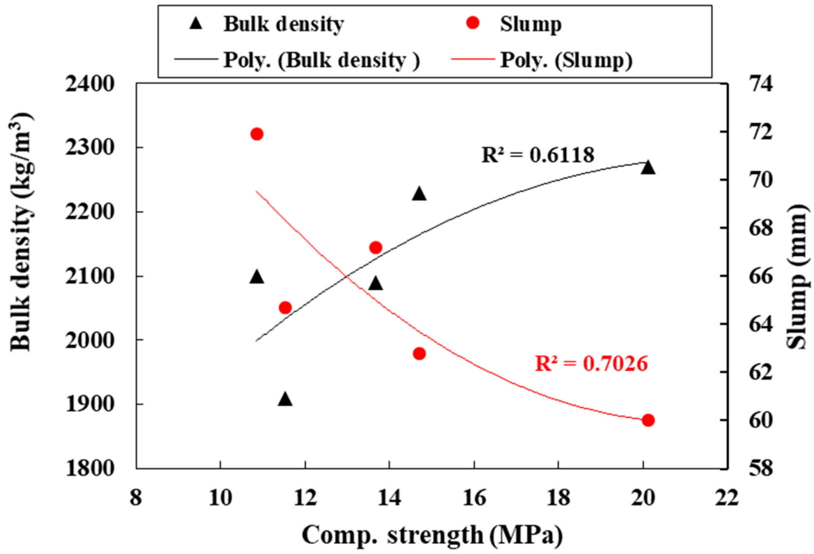

Figure 8. Relationship among compressive strength, bulk density, and slump of different mixes of concrete tested in this study.

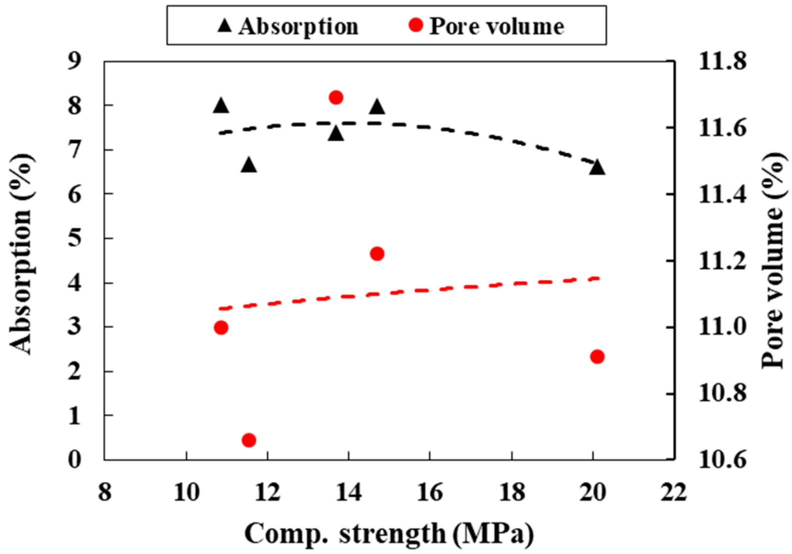

Figure 9. Relationship among compressive strength, absorption, and pore space of different mixes of concrete tested in this study.

3.5. Analysis of Variance (ANOVA) Test Results

The ANOVA single factor test was performed at a 95% significance level to observe any statistical relationships between all the concrete mixes corresponding to their properties, such as compressive strength, split tensile strength, water absorption, and pore spaces. As reported in Table 2, it can be seen that the p-value is less than 0.05 (for a 95% significance level) in all cases except for the result of the split tensile strength evaluation. Hence, no statistically significant relationship between the WCTA at 5% and 10% to the compressive strength, water absorption, and pore space was found. However, a statistical significance exists between the WCTA content and the splitting tensile strength.

Table 2. ANOVA test results for different concrete mixes and properties.

Groups	Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Test	*p*-Value	Significance
WCTA mixes to compressive strength	Between Groups	1	312.21	312.21	39.07	0.00025	No
	Within Groups	8	63.92	7.99			
WCTA mixes to split strength	Between Groups	1	3.13	3.13	2.42	0.1584	Yes
	Within Groups	8	10.37	1.29			
WCTA mixes to water absorption	Between Groups	1	47.22	47.22	31.97	0.00048	No
	Within Groups	8	11.81	1.48			
WCTA mixes to pore space	Between Groups	1	163.86	163.86	123.65	3.82×10^{-6}	No
	Within Groups	8	10.60	1.33			

3.6. Microstructural Analysis of Tire Concrete Using SEM

The microstructural analysis of hardened concrete with and without surface treatment of tire aggregate at 5% inclusion was performed using SEM image analysis, as shown in Figure 10. It can be seen that the treated tire surface became rough (see Figure 10b), which may have enhanced the bond between the rubber and matrix. In contrast, the rubber without surface treatment (see Figure 10a) seemed to have an even surface, which may have led to poor bond strength. Interestingly, in both cases (treated and untreated), a weak ITZ formed, as represented by a distinct line that creates a separation between tire aggregates and cement pastes, thus lowering the strength of the concrete. In conclusion, the surface treatment improved the bonding between aggregates and paste by making the tire aggregate surface abrasive, which, as a result, may improve the overall mechanical and durability properties of concrete.

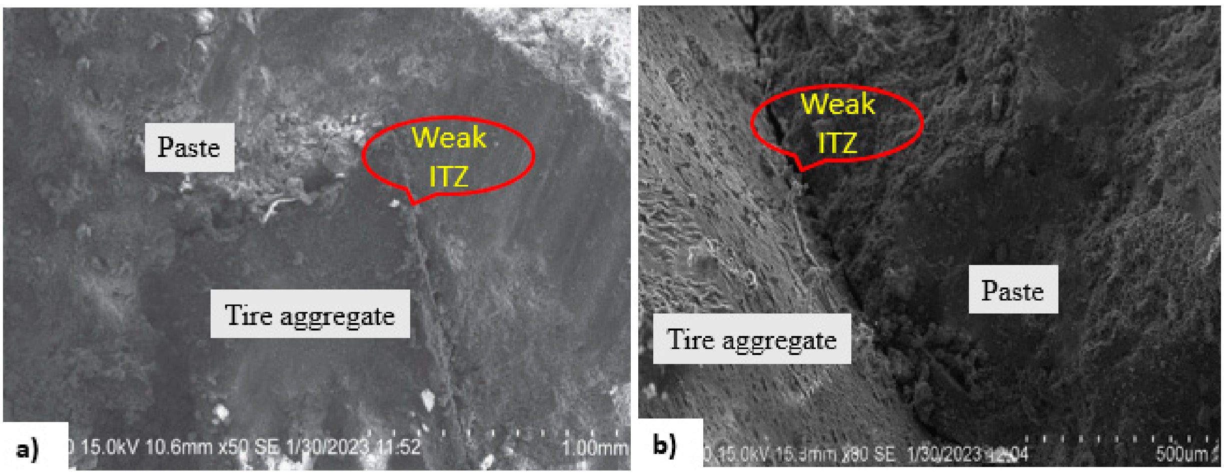

Figure 10. ITZ development between the cement paste and 5% tire aggregates (**a**) without surface treatment and (**b**) with surface treatment.

4. Conclusions

This study demonstrated the utilization of waste tire aggregate as a replacement for natural coarse aggregate in concrete production. Reusing waste tires in concrete, even at a low content, would reduce the hazardous pollution these tire stockpiles may cause. In addition, tire concrete has less density, higher ductility, and better noise and impact resistance, which are of the essence in many concrete applications. Based on experiments conducted in this study, the following conclusions can be drawn:

The slump of fresh concrete increases with the increment of tire aggregate percentages when it replaces coarse stone aggregate. A maximum of a 20% increase in the slump was recorded when untreated tire aggregate replaced 10% of the natural aggregate. However, a marginal increase (6.7%) in the slump was observed for the same level of the pretreated tire compared to the control.

Compared to the reference concrete, 5% and 10% untreated tire aggregate concrete demonstrated a considerable loss in the 28 days of compressive (about 32% to 46%) and split tensile (12% to 32%) strength. However, a slight improvement in strength was noticed when the tire aggregates were pretreated with cement coating, with optimal performance at 5% tire replacement.

Tire aggregate included at 5% and 10% and treated with a cement coating showed higher compressive strength and splitting tensile strength than untreated tire aggregate concrete.

The percentage of pore void space and absorption increased when natural stone aggregate was replaced by waste tire aggregates. This might be a consequence of water infiltration caused by poor adhesion between tire particles and the mixture. The tire aggregate inclusion of 10% showed better performance when compared with 5% tire aggregate in concrete.

A polynomial relationship could be found among the compressive strength, bulk density, and slump of tire concrete. However, no solid relationship was noticed among the compressive strength, water absorption, and pore spaces of tire aggregate concrete.

The surface treatment of the tire aggregate improves the bond strength between the aggregate and paste by developing a rough surface. However, a weak interfacial transition zone (ITZ) was formed with 5% and 10% tire inclusion in concrete. This weak ITZ could cause a lower strength of concrete with tire aggregate.

Statistical data comparisons of the properties of the studied concrete were made. No statistical significance was observed based on the relationships' *p*-values except for the relationship between the tire aggregate and the split tensile strength.

Research on the durability of concrete with tire aggregates is limited. Therefore, in future research, mesoscale and microscopic examinations should be performed regarding different properties, including the durability of tire concrete, to increase knowledge and confidence about using tire aggregates. For statistical comparisons using t-testing or ANOVA, more data would be required for the results to prove whether or not the data is statistically significant.

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