Water Absorption Comparison of Silane Treated and Untreated Recycled Concrete Aggregates

Steve Oteng-Owusu
Graduate Student
University of Windsor
Windsor, Ontario
otengow@uwindsor.ca

Abimbola Grace Oyeyi
Assistant Professor
University of Windsor
Windsor, Ontario
Grace.Oyeyi@uwindsor.ca

Paper prepared for the session SO - Innovation in Roadway/Embankment Materials and Geotechnical Engineering.

2026 Transportation Association of Canada (TAC) Conference & Exhibition
Winnipeg, Manitoba

Abstract

Recycled Concrete Aggregate (RCA) can reduce the consumption of natural aggregate and divert construction waste from landfills, but its porous residual mortar produces high water absorption that may limit its use in cold-region pavements. This study evaluated a commercial water-based solution containing 40% active silane as a treatment for RCA. Treated Recycled Concrete Aggregate (TRCA) and Untreated Recycled Concrete Aggregate (UTRCA) were obtained from the same parent material to reduce source-related variability. Water absorption and specific gravity were measured in triplicate in accordance with ASTM C127. The same three particles were photographed before and after treatment and analyzed using ImageJ, while Scanning Electron Microscopy (SEM) was used to examine surface features. Silane treatment reduced mean water absorption from 6.06 ± 0.08% to 2.53 ± 0.13%, corresponding to a 58.3% reduction. Changes in specific gravity were smaller than the change in absorption. ImageJ results showed limited changes in mean circularity (0.741 to 0.722), aspect ratio (1.432 to 1.430), roundness (0.699 to 0.701), and solidity (0.956 to 0.950). SEM images also showed a more uniform surface appearance after treatment, although the images did not establish chemical composition. The findings demonstrate that the selected silane treatment substantially reduced RCA water absorption without materially changing particle shape.

Keywords: Recycled Concrete Aggregate; silane treatment; water absorption; particle shape; ImageJ; scanning electron microscopy

Introduction

Concrete is widely used in buildings, roads, bridges, and other infrastructure because of its durability, availability, and relatively low cost [1]. However, increasing production has raised concerns about the depletion of natural aggregate resources and the growing quantity of construction and demolition (C&D) waste. C&D waste represents a substantial proportion of global solid waste [2,3] and accounts for approximately 30% of municipal solid waste disposed of in Canadian landfills. Recycled concrete aggregate (RCA), produced by crushing concrete from demolished structures, can reduce natural aggregate consumption while diverting waste from landfills [4].

Despite these environmental benefits, RCA generally absorbs more water than natural aggregate because its porous residual mortar contains pores and small cracks [5]. This is particularly important for pavements in cold regions, where absorbed water can freeze and create pressure within the aggregate and surrounding concrete. Repeated freeze-thaw cycles can lead to microcracking, scaling, strength loss, and progressive surface deterioration [6]. Freeze-thaw damage becomes more likely as concrete approaches a critical degree of saturation, while the greater porosity of RCA can increase moisture movement and reduce freeze–thaw resistance [7]. High absorption can also complicate moisture control during concrete production. Reducing RCA water absorption may therefore support its use in cold-region pavement applications.

Several treatment methods have been proposed to improve RCA quality, including mortar removal, surface coatings, and chemical treatments [8]. Silane was selected because it can reduce water penetration without mechanically removing the residual mortar [9]. It enters accessible surface pores and produces a water-repellent effect. In this study, we sourced a commercial water-based solution containing 40% active silane from Sika and used it as supplied to assess how effectively it reduced water absorption relative to untreated RCA. The study evaluated this product rather than identifying an optimum silane concentration.

Previous studies have investigated silane-treated RCA; however, treated and untreated aggregates have often been obtained from different sources. Because RCA properties depend on the composition, strength, age, and condition of the parent concrete, source variation can obscure the effect of treatment. This study addresses that limitation by comparing TRCA and UTRCA obtained from the same parent material. ASTM C127 testing measured water absorption and specific gravity, ImageJ provided a paired comparison of particle shape, and SEM examined visible surface differences. Together, these methods assessed whether treatment reduced water uptake without reshaping the aggregate.

2. Experiments and Methods

2.1 Materials

RCA used in this study was obtained from Walker Aggregates, Windsor, ON. The aggregate was sieved to obtain particles within the 4.75–19 mm size range. A water-based silane containing 40% alkylalkoxysilane, supplied by Sika Industries, was used as the treatment material. Both untreated recycled concrete aggregate (UTRCA) and treated recycled concrete aggregate (TRCA) originated from the same parent material. Using aggregates from the same source helped minimize variations in aggregate quality and allowed a more reliable assessment of the effect of silane treatment.

2.2 RCA Treatment Preparation

The preparation of silane-treated recycled concrete aggregate (TRCA) was carried out using a controlled procedure to ensure consistency throughout the study. Before treatment, the untreated recycled concrete aggregate (UTRCA) was thoroughly washed to remove dust, loose particles, and other surface impurities that could interfere with the interaction between the silane solution and the adhered mortar.
Following washing, the aggregates were oven-dried at 110°C for 24 hours to eliminate residual moisture and facilitate the penetration of the silane solution. After drying, the aggregates were sieved to obtain particles within the 4.75–19 mm size range. Maintaining a consistent particle size distribution helped ensure uniformity and reduced the influence of finer particles on the absorption measurements.
The prepared RCA was then immersed in a 40% silane solution for 24 hours to allow sufficient penetration of the treatment into the adhered mortar. After the soaking period, the aggregates were removed from the solution and allowed to air-dry until reaching a saturated surface-dry (SSD) condition. This ensured that excess surface moisture was removed while maintaining the internal moisture condition required for testing.

The treatment procedure adopted in this study was intended to provide a uniform application of the silane and improve the repeatability of the experimental results. A schematic illustration of the treatment process is presented in Figure 1.

Figure 1. RCA Silane Treatment Process



2.2 Microstructure (SEM)

To evaluate the effect of silane treatment on the surface morphology of recycled concrete aggregate, SEM analysis was conducted on both TRCA and untreated UTRCA. The primary objective was to examine changes in surface characteristics and assess potential modifications to the interfacial transition zones (ITZs) associated with the adhered mortar.

SEM imaging was performed using a JSM-7610F field emission scanning electron microscope. Representative aggregate samples from both TRCA and UTRCA were selected and prepared for analysis. Prior to imaging, samples were oven-dried to remove residual moisture and ensure image clarity. The specimens were then mounted and coated with a thin conductive layer to enhance imaging quality and prevent charging effects during observation.

Microstructural observations focused on identifying differences in surface texture, pore structure, and the presence of treatment-related features. Focus was given to variations in contrast and surface uniformity, which may indicate the distribution of silane within the adhered mortar and its potential influence on pore accessibility. These observations were used to support the interpretation of macroscopic properties, particularly water absorption behavior.

2.3 Physical Analysis of Aggregates

ImageJ image-processing software was used to determine whether silane treatment caused noticeable changes in aggregate shape. Three individual RCA aggregates were selected and photographed before treatment. The same aggregates were photographed again after silane treatment, allowing their shape characteristics to be compared directly. Images were converted to 8-bit format and thresholded to separate each particle from the background. Particle regions were filled, and the Analyze Particles function was used to generate outlines and obtain measurements. The same image-processing settings were applied to the before- and after-treatment images. The measured parameters included area, perimeter, major and minor axes, circularity, roundness, aspect ratio, and solidity. Circularity and roundness were the main shape indicators, while aspect ratio and solidity described particle elongation and boundary compactness, respectively.

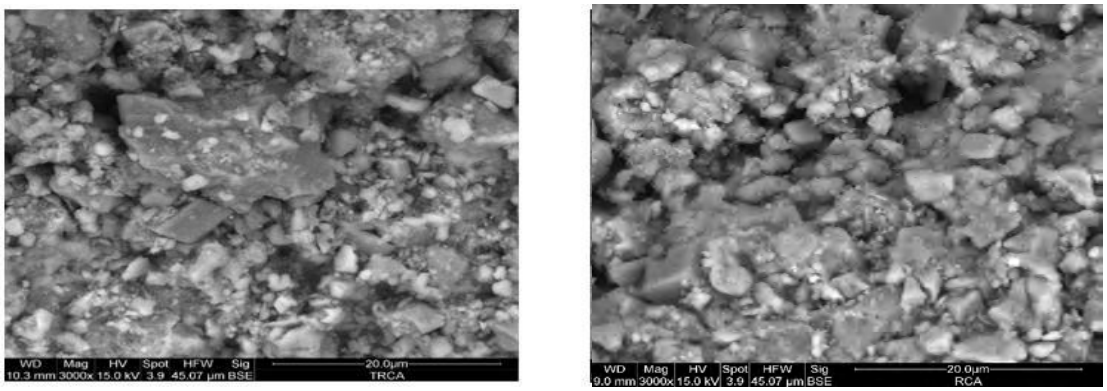
3. Results & Discussion

3.1 SEM Analysis

Figure 2 presents the SEM images obtained for TRCA and UTRCA. Visible differences in surface appearance were observed between the two samples. The treated aggregates generally exhibited lighter and more uniform surface regions, whereas the untreated aggregates showed comparatively rougher and less homogeneous surfaces.

Although SEM observations alone cannot confirm the chemical composition of these features, the differences observed suggest that the silane treatment modified the surface characteristics of the adhered mortar. These observations are consistent with the reduction in water absorption obtained from the ASTM C127 tests. The SEM analysis provided qualitative evidence supporting the effectiveness of the treatment. However, additional characterization techniques such as Energy-Dispersive Spectroscopy (EDS) would provide a better understanding of the interaction between the silane and the adhered mortar.

Figure 2. SEM Comparative analysis between TRCA and UTRCA



TRCA UTRCA

3.2 Water Absorption

Table 1 presents the ASTM C127 results for TRCA, and Table 2 presents the corresponding UTRCA results. The three TRCA batches produced absorption values between 2.40% and 2.65%, whereas the UTRCA values ranged from 5.98% to 6.13%. Silane treatment reduced mean water absorption from 6.06 ± 0.08% for UTRCA to 2.53 ± 0.13% for TRCA, a reduction of approximately 58.3%. The narrow range within each group shows that the repeated measurements were reasonably consistent. Because both groups were obtained from the same parent aggregate and tested using the same procedure, the measured difference is more directly associated with the silane treatment than with source variation.

Table 1. Water Absorption Test Results for TRCA

Batch	Bulk SG (Dry)	Bulk SG (SSD)	Apparent SG	Absorption (%)
Batch 1	2.363	2.420	2.552	2.400
Batch 2	2.340	2.400	2.538	2.550
Batch 3	2.319	2.381	2.520	2.650
Average	2.341	2.401	2.537	2.53

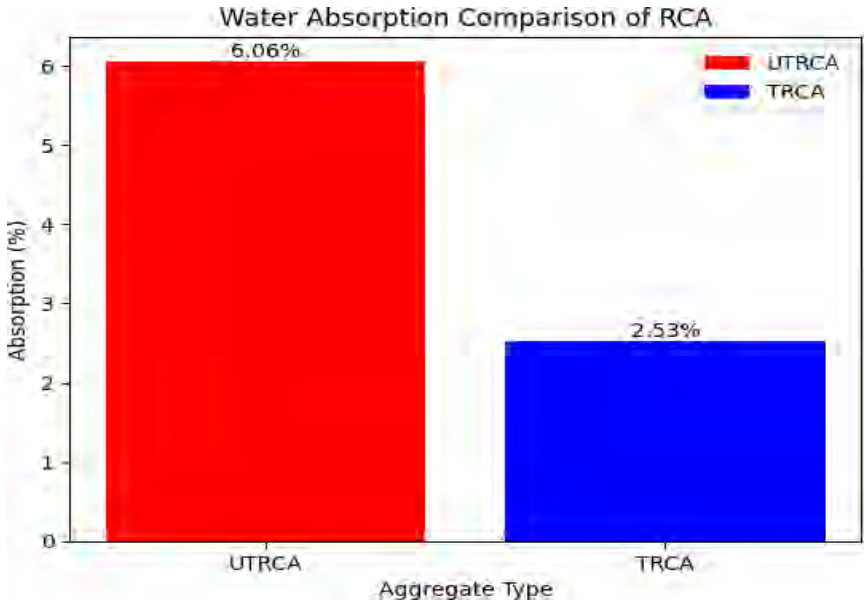
Table 2. Water Absorption Test Results for UTRCA

Batch	Bulk SG (Dry)	Bulk SG (SSD)	Apparent SG	Absorption (%)
Batch 1	2.305	2.446	2.715	6.13
Batch 2	2.321	2.448	2.728	5.98
Batch 3	2.301	2.432	2.712	6.07
Average	2.309	2.442	2.718	6.06

The oven-dry bulk specific gravity increased slightly from 2.309 for UTRCA to 2.341 for TRCA. In contrast, SSD bulk specific gravity decreased from 2.442 to 2.400, and apparent specific gravity decreased from 2.718 to 2.537. These values show that the treatment did not produce a uniform increase or decrease across all specific-gravity measures. The changes were nevertheless smaller than the 58.3% reduction in absorption, indicating that the clearest treatment effect was the reduction in water uptake. The lower absorption suggests that silane restricted water entry into part of the accessible pore system within the residual mortar.

On average, UTRCA absorbed approximately 2.4 times as much water as TRCA. This comparison is important because the residual mortar is the main source of the higher absorption associated with RCA. Limiting water entry into this material directly addresses the property that distinguishes RCA from denser natural aggregate. The ASTM C127 results therefore provide a clear measure of treatment performance at the aggregate level, although they do not reproduce the loading, moisture movement, or freezing conditions experienced by concrete in service.

Figure 3. Water absorption comparison between untreated (UTRCA) and silane-treated RCA (TRCA)



The results establish the effectiveness of the selected 40% active-silane product under the treatment conditions used in this study. Lower aggregate absorption could reduce the amount of water available within the residual mortar during freezing and may help control moisture exchange when RCA is introduced into a concrete mixture. However, these possible concrete-level benefits were not measured in the present aggregate study. The results also do not establish that the 40% formulation is more effective or economical than the 4–12% concentrations commonly used in practice because concentration and cost were not experimental variables. A dosage study is required to identify the lowest concentration that can provide an acceptable reduction in absorption and to compare material and treatment costs. Concrete testing is also required to determine whether the measured absorption reduction improves strength or freeze–thaw durability.

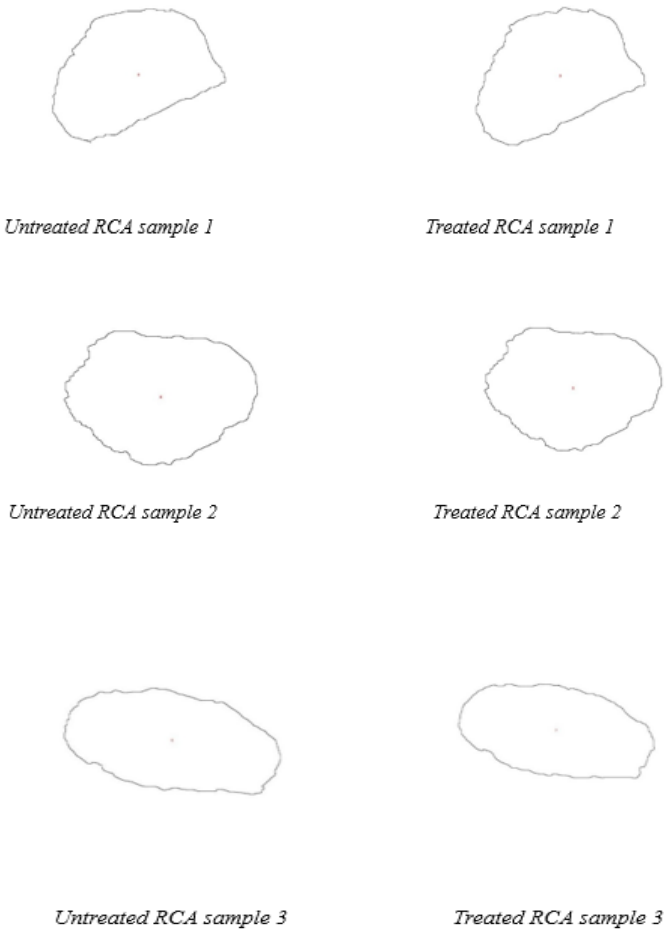
3.3 Physical Shape Analysis of Aggregates

The same three RCA aggregates were analysed before and after silane treatment using ImageJ. The mean circularity changed slightly from 0.741 to 0.722, while the aspect ratio remained nearly unchanged at 1.432 and 1.430, respectively. Similarly, roundness changed from 0.699 to 0.701 and solidity from 0.956 to 0.950 (Table 3). The overlapping aggregate outlines and small differences between the measured values indicate that the treatment did not cause substantial rounding, smoothing, or reshaping of the aggregates, as seen in Figure 4. This result is consistent with the non-mechanical action of silane, which penetrates accessible pores and reduces water entry without applying abrasive forces to the particle surface. Overall, the results show that silane treatment reduced water absorption without materially altering the original shape and angular characteristics of the RCA aggregates.

Table 3: Particle-shape parameters of untreated RCA determined using ImageJ

Particle	RCA condition	Circularity	Aspect ratio	Roundness	Solidity
1	Treated	0.679	1.518	0.659	0.947
1	Untreated	0.713	1.517	0.659	0.948
2	Treated	0.762	1.380	0.725	0.953
2	Untreated	0.765	1.387	0.721	0.961
3	Treated	0.725	1.391	0.718	0.950
3	Untreated	0.746	1.393	0.718	0.960
Mean	Treated	0.722	1.430	0.701	0.950
Mean	Untreated	0.741	1.432	0.699	0.956

Figure 4: Particle-shape parameters of untreated RCA determined using ImageJ



4.0 Conclusion

This study compared untreated and silane-treated RCA obtained from the same parent material. Under the treatment conditions used, the 40% active, water-based silane solution reduced mean water absorption from 6.06 ± 0.08% to 2.53 ± 0.13%, corresponding to a 58.3% reduction. The specific-gravity results changed less than water absorption, showing that reduced water uptake was the principal measured effect.

ImageJ analysis of the same three particles before and after treatment found only small changes in circularity, aspect ratio, roundness, and solidity. The treatment therefore reduced water absorption without materially changing particle shape. SEM images showed a more uniform surface appearance after treatment, but chemical analysis is required to identify the composition of the observed surface features.

The use of treated and untreated aggregates from the same parent material was central to the study because it reduced the influence of differences in the original concrete. The findings demonstrate the effectiveness of the selected commercial silane product for reducing the water absorption of same-source RCA. However, the study did not compare silane concentrations, treatment costs, or concrete-level durability. Future work should evaluate lower silane concentrations, treatment economics, and the mechanical and freeze–thaw performance of concrete containing TRCA before field application is recommended.

References

[1] M. Abdul Basit, N. M. Sadiqul Hasan, M. Jihad Miah, and S. Chandra Paul, "Strength and cost analysis of concrete made from three different recycled coarse aggregates," *Mater. Today Proc.*, Mar. 2023, doi: 10.1016/J.MATPR.2023.03.247.

[2] V. W. Y. Tam, M. Soomro, and A. C. J. Evangelista, "A review of recycled aggregate in concrete applications (2000–2017)," *Constr. Build. Mater.*, vol. 172, pp. 272–292, May 2018, doi: 10.1016/J.CONBUILDMAT.2018.03.240.

[3] N. Islam, M. Sandanayake, S. Muthukumaran, and D. Navaratna, "Review on Sustainable Construction and Demolition Waste Management—Challenges and Research Prospects," *Sustainability 2024, Vol. 16, Page 3289*, vol. 16, no. 8, p. 3289, Apr. 2024, doi: 10.3390/SU16083289.

[4] K. McNeil and T. H. K. Kang, "Recycled Concrete Aggregates: A Review," *International Journal of Concrete Structures and Materials 2013 7:1*, vol. 7, no. 1, pp. 61–69, Mar. 2013, doi: 10.1007/S40069-013-0032-5.

[5] Ozbakkaloglu, T., Gholampour, A., & Xie, T. (2017). Mechanical and Durability Properties of Recycled Aggregate Concrete: Effect of Recycled Aggregate Properties and Content. *Journal of Materials in Civil Engineering*, *30*(2), 04017275. https://doi.org/10.1061/(ASCE)MT.1943-5533.0002142

[6] Guler, S., & Akbulut, Z. F. (2025). A comprehensive review of concrete durability in freeze-thaw conditions: Mechanisms, prevention, and mitigation strategies. *Structures*, *75*, 108804. https://doi.org/10.1016/J.ISTRUC.2025.108804

[7] Zou, D., Wang, Z., Shen, M., Liu, T., & Zhou, A. (2021). Improvement in freeze-thaw durability of recycled aggregate permeable concrete with silane modification. *Construction and Building Materials*, *268*, 121097. https://doi.org/10.1016/J.CONBUILDMAT.2020.121097

[8] C. Shi, Y. Li, J. Zhang, W. Li, L. Chong, and Z. Xie, "Performance enhancement of recycled concrete aggregate – A review," *J. Clean. Prod.*, vol. 112, pp. 466–472, Jan. 2016, doi: 10.1016/J.JCLEPRO.2015.08.057.

[9] Y. G. Zhu, S. C. Kou, C. S. Poon, J. G. Dai, and Q. Y. Li, "Influence of silane-based water repellent on the durability properties of recycled aggregate concrete," *Cem. Concr. Compos.*, vol. 35, no. 1, pp. 32–38, Jan. 2013, doi: 10.1016/J.CEMCONCOMP.2012.08.008.