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Effect of Carbonation Treating Recycled Aggregates on Mechanical Properties of Concrete

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ABSTRACT

Numerous studies have suggested using recycled concrete aggregates (RCA) as a possible alternative to natural aggregates in the manufacture of concrete because of the financial and environmental advantages that come with it. However, RCA's engineering qualities are inferior to those of natural aggregates (NA) because of its high water absorption. In order to improve the mechanical and durability qualities of RCA, researchers have proposed a number of pretreatment techniques, such as thermal, mechanical, and chemical treatment. This experimental study examined the effects of carbonation treating RCA on the compressive strength and indirect tensile strength of concrete that substituted varying amounts of RCA (0, 20, 30, 40, 50, and 100 % by weight) for 10-20 mm natural coarse aggregate. The study's findings indicate that, adding recycled concrete aggregates to concrete mixtures can have a detrimental influence on the mixes' compressive and tensile strengths; however, this effect can be lessened by carbonation treating the recycled aggregates. Replacing 100% of carbonated aggregate leads to approximately 14 and 23% enhancements in the compressive and tensile strengths of concrete, respectively, when compared to concrete made with 100% untreated recycled aggregate.

Keywords: Recycled aggregates, Replacement level, Carbonation, Compressive Strength, Splitting Tensile Strength.

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تأثير المعالجة بالكربنة للركام المعاد تدويره على الخواص الميكانيكية للخرسانة

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الملخص

اقترحت العديد من الدراسات استخدام الركام الخرساني المعاد تدويره (RCA) كبديل محتمل للركام الطبيعي في صناعة الخرسانة، نظرًا للمزايا المالية والبيئية المصاحبة له. ومع ذلك، فإن الخصائص الهندسية للركام المعاد تدويره أقل جودة من الركام الطبيعي (NA) بسبب ارتفاع امتصاصه للماء. ولتحسين الخصائص الميكانيكية والمتانة للركام المعاد تدويره، اقترح الباحثون عددًا من تقنيات المعالجة المسبقة مثل المعالجة الحرارية والميكانيكية والكيميائية.

وقد تناولت هذه الدراسة المعملية تأثير معالجة الكربنة للركام الخرساني المعاد تدويره على مقاومة الضغط ومقاومة الشد غير المباشر للخرسانة، حيث تم استبدال نسب مختلفة من الركام المعاد تدويره (0، 20، 30، 40، 50، 100% بالوزن) من الركام الخشن الطبيعي بحجم 10–20 مم.

تشير نتائج الدراسة إلى أن إضافة الركام الخرساني المعاد تدويره إلى الخلطات الخرسانية يمكن أن يكون له تأثير سلبي على مقاومة الضغط ومقاومة الشد لهذه الخلطات، إلا أن هذا التأثير يمكن تقليله من خلال المعالجة بالكربنة للركام المعاد تدويره. كما تبين أن استبدال 100% من الركام بالكربنة يؤدي إلى تحسن يقارب 14% في مقاومة الضغط و23% في مقاومة الشد للخرسانة، مقارنة بالخرسانة المصنوعة من 100% من الركام المعاد تدويره غير المعالج.

الكلمات المفتاحية: الركام المعاد، مستوى الاستبدال، الكربنة، مقاومة الضغط، مقاومة الشد الانشطاري.

INTRODUCTION

Recycled concrete aggregates (RCAs) have gained significant attention as a sustainable alternative to natural aggregates in the construction industry. As the demand for environmentally friendly construction practices increases, the reuse of demolition waste in the

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form of RCAs provides an effective solution to reduce the depletion of natural resources and minimize construction waste. Recycled concrete aggregates generates less CO_2 emission as compared to natural aggregates when life cycle assessment is taken into account [1, 2] and are more cost-effective alternative to natural aggregate [2]. However, one of the major challenges of using RCAs is their inferior quality compared to natural aggregates due to the presence of adhered mortar and impurities, which can negatively affect the mechanical properties of concrete. Replacement of natural aggregate (NA) with recycled concrete aggregate leads to high porosity [3], high permeability [4] and decrease in density and specific gravity of recycled concrete aggregate [5]. Furthermore, RCA has rough, non-homogenous, granular or crystalline surface texture [5, 6]. The replacement of natural aggregates with recycled concrete aggregates leads to decrease in workability of fresh concrete [7] and reduction in compressive strength, modulus of elasticity and shear strength in hardened concrete [8]. The inferior properties of recycled concrete aggregates are mainly due to presence of adhered mortar on the surface of recycled concrete aggregates. This attached mortar is highly porous in nature because of which recycled concrete aggregate have high water absorption rate [9] and weaker interfacial transition zone. The water absorption rate of recycled concrete aggregate is influenced by various factors such as larger size aggregates [10], quality of recycling procedure and strength of original concrete [11]. In order to improve recycled concrete aggregate properties, the interfacial transition zone needs to be strengthened [12] through combination of pretreatment methods. To address this issue, various treatments have been developed to enhance the quality of RCAs [13- 25]. Among the various approaches applied to treat recycled concrete aggregates (RCAs), accelerated carbonation stands out because it not only enhances the quality of RCAs but also provides a permanent method for capturing carbon dioxide (CO_2). It has been estimated that one ton of cement present in RCAs can theoretically absorb around 0.5 tons of CO_2 [26]. Moreover, studies have shown that accelerated carbonation can lower the water absorption of RCAs sized 5-10 mm and 10-20 mm by up to 30% and 22%, respectively, while also increasing their apparent density by as much as 4.8% and 3.2% [27]. Mechanical properties, such as compressive and flexural strength, remain largely unaffected until the proportion of natural aggregates replaced by carbonated RCAs exceeds 40% [28]. In recent years,

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this technique has gained significant attention because of its remarkable advantages in improving RCA performance. The impact of carbonation treating recycled concrete aggregates (CRCA) on the concrete's compressive and tensile strengths after 28 days of curing is being investigated in this experimental study. Eleven distinct concrete mixture types were created by substituting treated and non-treated recycled aggregates for natural coarse aggregates in varying weight percentages (0, 20, 30, 40, 50, and 100%). Additionally, carbonation depth of treated and non-treated recycled aggregates were examined.

EXPERIMENTAL PROGRAM

Materials

In this research, a commercial CEMI 42.5N cement was utilized. This cement complies with the standards outlined in BS EN 197-1:2000. The physical and chemical properties of the cement are presented in Table 1. The recycled concrete aggregates required for the experimentation were collected from demolished concrete waste of 6 story building in Benghazi (Figure 1). The concrete blocks were crushed manually into combined various sizes and later on separated into 20 mm, 10 mm and 5 mm size aggregates. The sieve analysis of aggregates was carried out in accordance with BS 812-103.1:1985. The physical properties of natural aggregates & recycled concrete aggregates including specific gravity and water absorption were obtained in accordance with BS 812-2:1995 as shown in Table 2. Natural sand with an apparent specific gravity of 2.50 and absorption of 0.66% was used. The sieve analysis results of the recycled coarse and fine aggregates used in the concrete mixtures are given in Table 3. Potable tap water available at the laboratory used in concrete mixtures in this research.

Table 1. Physical and chemical analysis of used cement

Item	Cement
Physical properties	
Specific gravity (g/cm^2)	3.13
Fineness (m^2/kg) (Blaine)	320
Chemical properties (Oxides, % by weight)	
SiO_2	20.86
Al_2O_3	5.6
CaO	62.39
Fe_2O_3	4
MgO	1

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SO_3	2.93
K_2O	-
L.O.I	2.52

Figure 1. Demolished building.

Table 2. Properties of natural aggregates & recycled coarse aggregates

Type of aggregate	NA	RCA
Specific density	2,54	2.40
Water absorption (%)	2.53	6.35
Impact Value (%)	18	29.7

Table 3. Sieve analysis of coarse and fine aggregates

Sieve (mm)	Passing (%)	
	Coarse	Fine
20	100	-
14	79	-
10	35	-
5	2	100
2.36	0.1	100
1.18	-	98.92
0.6	-	85.86
0.3	-	9.86
0.15	-	0.08

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Carbonation treating method

A metal container for carbonation processing was fabricated from iron with a thickness of 4 mm and a dimensions of 1m × 1m × 0.5m. Figure 2 shows the carbonation chamber, which is equipped with a gauge for measuring internal pressure. The recycled coarse aggregates (RCA) were first soaked in a 0.01mol calcium hydroxide solution for 24 hours, followed by air-drying for 3 days. The aggregates were then placed in the carbonation chamber (Figure 2), where the air was evacuated, and carbon dioxide was pumped into the chamber until a pressure of 1 bar was reached. Afterward, the aggregates were left in the carbonation chamber for 24 hours. Once the treatment was complete, the treated recycled coarse aggregates were placed in a tightened bag, ready for use in the experiment. The method used in this study is based on the procedure outlined by Pan et al. [29]. Figure 3 shows the appearance of RCA before treatment.

Figure 2. Carbonation chamber attached to the CO_2 container.


0

Figure 3. RCA before treatment.

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Proportions and mixing procedure

Mix design proportioning was performed by using weight-batching method and was designed in accordance with the Building Research Establishment (British method). Proportioning of concrete mixtures is shown in Table 4. All mixtures were mixed in a laboratory pan mixer with a volume capacity of 0.06 m^3. The mix ingredients placed in the mixer was in the following order; coarse aggregate, cement, and fine aggregate. The dry mix ingredients were mixed in the mixer for 30 seconds. Then, water was added gradually in 15 seconds and the mixing continued for 2.5 minutes. Therefore, the total mixing time was 3 minutes for each concrete mixture. After mixing, the molds were filled with concrete and properly compacted by means of a vibrating table. The top surface was leveled and finished by trowel.

Table 4. Proportions for concrete mixes

Rep. Level (%)	Kg/m^3						
	Cement	Water	Sand	Coarse aggregate			
				NA	NA	RCA	CRCA
				5-10 mm	10-20 mm	10-20 mm	10-20 mm
0	350	175	630	380	880	-	-
20	350	175	630	380	704	176	-
30	350	175	630	380	616	264	-
40	350	175	630	380	528	352	-
50	350	175	630	380	440	440	-
100	350	175	630	380	-	880	-
20	350	175	630	380	704	-	176
30	350	175	630	380	616	-	264
40	350	175	630	380	528	-	352
50	350	175	630	380	440	-	440
100	350	175	630	380	-	-	880

NA: Natural aggregate; **RCA:** Recycled concrete aggregate; **CRCA:** Carbonation treating recycled concrete aggregate.

Curing of specimens

After casting, the concrete specimens were covered with thin polythene sheets and left to cure under laboratory conditions for a period of 24 hours. Thereafter, the specimens were de-moulded and stored in curing water at around 20°C until test age.

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Testing of specimens

The standard cylinder of 100 mm diameter × 200 mm height was used for indirect tensile strength and tested according to BS 1881-117:1983 and compressive strength was performed on 100 mm cube according to BS1881-116:1983. The workability of freshly mixed concrete was measured by using slump test according to BS1881-102: 1983. The depth of carbonation for RCA after treatment was also assessed using phenolphthalein solution. A sample of treated aggregates was taken and broken using hammer and chisel to expose the internal surface. The surface of RCA was then sprayed with a phenolphthalein solution. Aggregate's water absorption and specific gravity tests were conducted following BS 812-2:195, and aggregate's impact value test was carried out according to BS 812-3:1975.

RESULTS AND DISCUSSION

Properties of aggregates

Table 5 presents the specific gravity, water absorption and impact value's results of natural and recycled aggregates before and after treatment. The specific gravity of the NA is 2.54, while that of the RCA is 2.40, making RCA 3.05% lower in density compared to NA. The specific gravity of CRCA is 2.45, representing a 2.04% improvement compared to the untreated RCA. It can be also seen from the results that the impact strength of RCA is 65% lower compared to NA. The impact strength of CRCA is 25.3%, representing a 14.8% improvement compared to the RCA. According to the absorption results shown in Table 3, absorbency of NA is 2.53%, while that of RCA is 6.35%. The absorbency of the RCA is approximately 2.5 times higher compared to the NA. The absorption value of the CRCA is 5.12%, representing a 19.37% improvement compared to that of the untreated RCA. According to the absorption results shown in Table 5

Table 5. Water absorption and impact values of aggregates

Type of aggregate	NA	RCA	CRCA
Specific gravity	2,54	2.40	2.45
Water absorption (%)	2.53	6.35	5.12
Impact Value (%)	18	29.7	25.3

Carbonation depth

Figure 4 shows the appearance of the RCA and CRCA before and after spraying with the phenolphthalein solution. It can be observed

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that the color of the CRCA does not change, which indicates that the carbonation process has a significant effect on the surface of the CRCA. When compared to the untreated RCA, which changes its color to pink after spraying with the solution, the CRCA does not undergo any color change. This indicates that the carbonation treatment process effectively altered the aggregate's nature from alkaline to neutral, thereby preventing any color change. This suggests that the carbonation treatment significantly affected the interior of the completely CRCA and modified its properties. This observation is consistent with the findings reported in research by Gholizadeh-Vayghan et al. [30].

Figure 4. Aggregates before and after spraying the phenolphthalein.

Compressive strength

Figure 5 shows the compressive strength results of concrete mixes. At the 0% replacement level, the compressive strength is approximately 45 MPa, which serves as the reference strength. As the replacement level increases, the RCA mix shows a gradual and consistent decline in compressive strength. By 100% replacement, the strength drops to about 38 MPa, representing a significant reduction of 14.5% compared to the control mix. Gerardo et al. [31] reported that the incorporation of recycled aggregates leads to a reduction in compressive strength ranging from approximately 2.6% to 43% compared to concrete produced with natural aggregates, with the extent of this reduction being influenced by the level of aggregate replacement. According to Fellah et al. [32], the replacement of natural aggregates by recycled ones at rates of 25%

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and 75% resulted in decreases in compressive strength of 2.6% and 8.44%, respectively.

In contrast, the CRCA mix demonstrates remarkable stability in compressive strength across the replacement levels. While there is a slight downward trend, the strength remains close to 44 to 45 MPa, even at 100% replacement. The steady decline in compressive strength with increasing RCA replacement suggests that the quality of RCA may be compromised by factors such as higher porosity, weaker adhered mortar, and micro-cracks. This leads to reduced mechanical interlocking and weaker interfacial transition zones, which negatively affect compressive strength. The relatively stable compressive strength of CRCA concrete indicates that the carbonation process potentially improves recycled aggregate quality by reducing its porosity. Xuan and Poon [28] reported that the compressive and flexural strengths remain largely unaffected until the replacement of natural aggregates with carbonated RCAs exceeds 40%.

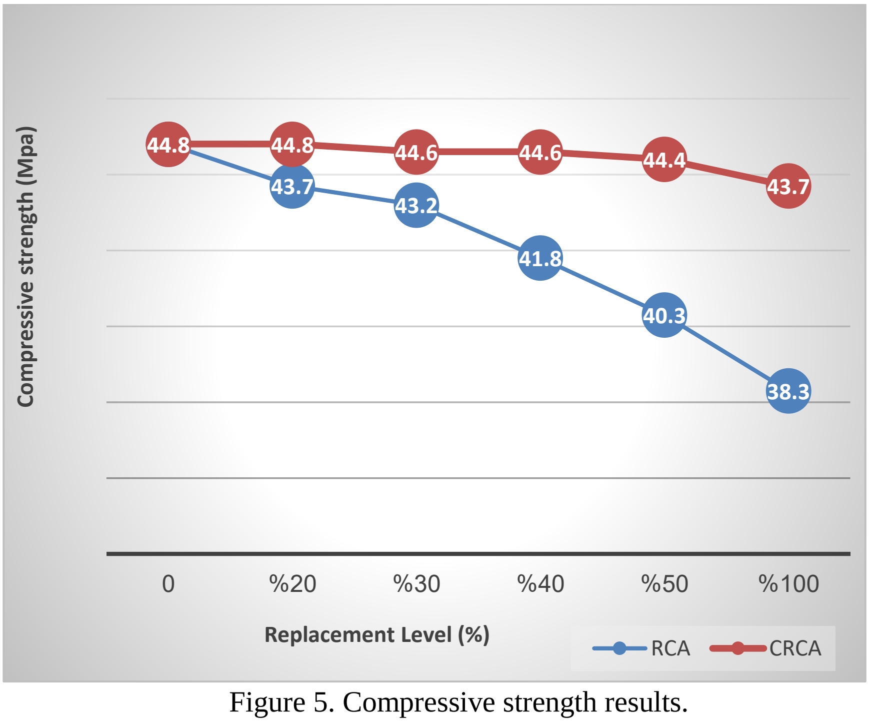

Figure 5. Compressive strength results.

Splitting tensile strength

Figure 6 shows the results of the splitting tensile strength for concrete specimens. It can be seen from the graph that the splitting tensile strength of recycled aggregate (RCA) concrete exhibits a

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consistent reduction as the replacement level increases. Specifically, the strength decreases from approximately 3.0 MPa at 0% replacement to around 2.0 MPa at 100% replacement.
In comparison, concrete incorporating carbonated recycled aggregate (CRCA) also demonstrates a decline in tensile strength with increasing replacement levels; however, the rate of reduction is less pronounced (see Figure 6). At all replacement levels, CRCA maintains higher tensile strength than RCA. Notably, at 100% replacement, CRCA achieves a value of approximately 2.5 MPa, whereas RCA falls to about 2.0 MPa. These results indicate that CRCA consistently outperforms RCA, exhibiting superior strength retention and thus representing a more effective aggregate alternative, particularly at higher replacement percentages.

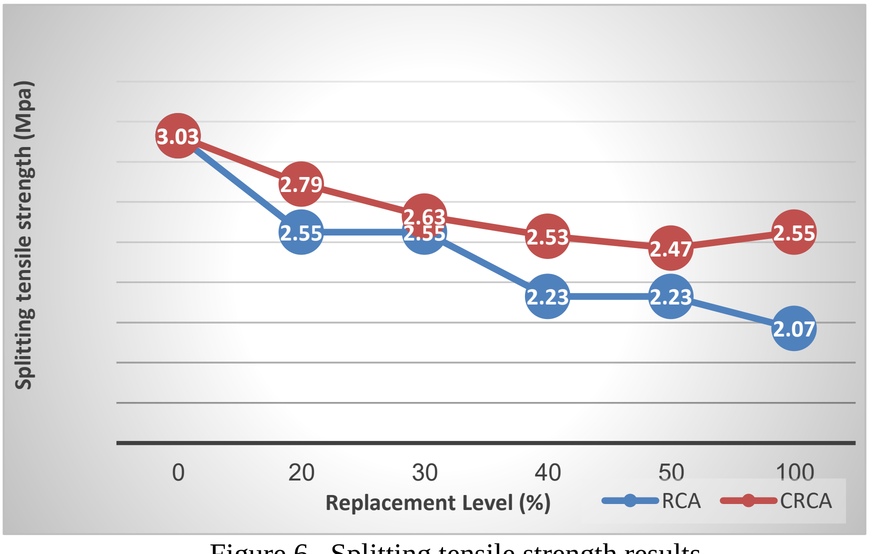

Figure 6. Splitting tensile strength results.

CONCLUSION
According to the test results, the following main findings can be drawn from this investigation:

- In comparison to natural aggregates, recycled concrete aggregates (RCA) exhibit higher water absorption, lower density, and greater impact values. However, carbonation treatment of RCA has been shown to enhance its physical and mechanical properties.

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- Incorporating recycled concrete aggregates (RCA) into concrete mixes can impact both compressive and splitting tensile strengths negatively, but carbonation treatment of recycled aggregates can help mitigate this effect. The complete substitution of untreated recycled aggregate with carbonated recycled aggregate results in an approximate improvement of 14% in compressive strength and 23% in tensile strength, relative to concrete produced with 100% untreated recycled aggregate.

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REFERENCES

[1] Huang, B., Wang, X., Kua, H., Geng, Y., Bleischwitz, R., & Ren, J. (2019). Construction and demolition waste management in China through the 3R principle. *Resources, Conservation and Recycling*, *129*, 36-44. https://doi.org/10.1016/j.resconrec.2017.09.029

[2] Rampit, R. A., Singh, A., & Kumar, R. (2020). Life cycle assessment of recycled aggregate concrete: A review. *Journal of Cleaner Production*, *251*, 119710. https://doi.org/10.1016/j.jclepro.2019.119710

[3] Gómez-Soberón, J. M. V. (2002). Porosity of recycled concrete with substitution of recycled concrete aggregate: An experimental study. *Cement and Concrete Research*, *32*(8), 1301-1311. https://doi.org/10.1016/S0008-8846(02)00795-0

[4] Dhir, R. K., de Brito, J., Silva, R. V., & Lye, C. Q. (2011). *Use of recycled aggregates in concrete*. Thomas Telford Publishing.

[5] Ho, N. Y., Lee, Y. P. K., Lim, W. F., Tam, C. T., & Lee, S. L. (2013). Influence of recycled concrete aggregates on the properties of concrete. *Magazine of Concrete Research*, *65*(2), 68-76. https://doi.org/10.1680/macr.12.00030

[6] Ouyang, W. (2021). Characteristics of recycled concrete aggregates and their influence on concrete properties. *Materials*, *14*(2), 312. https://doi.org/10.3390/ma14020312

http://www.doi.org/10.62341/maec2810

[7] Ismail, S., Rahman, I. A., & Ramli, M. (2020). The effect of recycled concrete aggregate on fresh and hardened properties of concrete. *IOP Conference Series: Materials Science and Engineering*, *712*(1), 012030. https://doi.org/10.1088/1757-899X/712/1/012030
[8] Rahal, K. (2007). Mechanical properties of concrete with recycled coarse aggregate. *Building and Environment*, *42*(1), 407- 415. https://doi.org/10.1016/j.buildenv.2005.07.033
[9] Malešev, M., Radonjanin, V., & Marinković, S. (2014). Recycled concrete as aggregate for structural concrete production. *Sustainability*, *6*(5), 2365-2379. https://doi.org/10.3390/su6052365
[10] Guerzou, S., Benabed, B., & Azzouz, L. (2018). Influence of aggregate size on the properties of recycled concrete aggregate. *Construction and Building Materials*, *170*, 574-584. https://doi.org/10.1016/j.conbuildmat.2018.03.101
[11] Silva, R. V., de Brito, J., & Dhir, R. K. (2014). Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. *Construction and Building Materials*, *65*, 201- 217. https://doi.org/10.1016/j.conbuildmat.2014.04.117
[12] Liu, Q., & Peng, Y. (2018). Improvement of interfacial transition zone in recycled concrete aggregate concrete. *Construction and Building Materials*, *167*, 757-768. https://doi.org/10.1016/j.conbuildmat.2018.02.102
[13] Ismail, S., & Ramli, M. (2014). Engineering properties of treated recycled concrete aggregate (RCA) for structural applications. *Construction and Building Materials*, *44*, 464-476. https://doi.org/10.1016/j.conbuildmat.2013.12.030
[14] Sereng, M., Djerbi, A., Metalssi, O. O., Dangla, P., & Torrenti, J.-M. (2021). Improvement of recycled aggregates properties by means of CO_2 uptake. *Applied Sciences*, *11*(14), 6571. https://doi.org/10.3390/app11146571
[15] Shi, C., Wu, Z., Cao, Z., Ling, T. C., & Zheng, J. (2018). Performance of mortar prepared with recycled concrete aggregate enhanced by CO_2 and pozzolan slurry. *Cement and Concrete Composites*, *86*, 130–138. https://doi.org/10.1016/j.cemconcomp.2017.10.013
[16] Wang, J., Zhang, J., Cao, D., Dang, H., & Ding, B. (2020). Comparison of recycled aggregate treatment methods on the performance for recycled concrete. *Construction and Building*

Materials, 234, 117366. https://doi.org/10.1016/j.conbuildmat.2019.117366

[17] Zhu, L., Ning, Q., Han, W., & Bai, L. (2022). Compressive strength and microstructural analysis of recycled coarse aggregate concrete treated with silica fume. *Construction and Building Materials, 334,* 127453. https://doi.org/10.1016/j.conbuildmat.2022.127453

[18] Zhang, J., Shi, C., Li, Y., Pan, X., Poon, C. S., & Xie, Z. (2015). Influence of carbonated recycled concrete aggregate on properties of cement mortar. *Construction and Building Materials, 98,* 1–7. https://doi.org/10.1016/j.conbuildmat.2015.07.150

[19] Zhan, B. J., Xuan, D. X., Poon, C. S., & Scrivener, K. L. (2020). Characterization of interfacial transition zone in concrete prepared with carbonated modeled recycled concrete aggregates. *Cement and Concrete Research, 136,* 106175. https://doi.org/10.1016/j.cemconres.2020.106175

[20] Zhan, B. J., Xuan, D. X., & Poon, C. S. (2018). Enhancement of recycled aggregate properties by accelerated CO_2 curing coupled with limewater soaking process. *Cement and Concrete Composites, 89,* 230–237. https://doi.org/10.1016/j.cemconcomp.2018.03.011

[21] Xuan, D., Zhan, B., & Poon, C. S. (2016). Assessment of mechanical properties of concrete incorporating carbonated recycled concrete aggregates. *Cement and Concrete Composites, 65,* 67–74. https://doi.org/10.1016/j.cemconcomp.2015.10.018

[22] Kazmi, S. M. S., Munir, M. J., Wu, Y. F., Patnaikuni, I., Zhou, Y., & Xing, F. (2019). Influence of different treatment methods on the mechanical behavior of recycled aggregate concrete: A comparative study. *Cement and Concrete Composites, 104,* 103398. https://doi.org/10.1016/j.cemconcomp.2019.103398

[23] Martínez-Echevarría, M., López-Alonso, M., Garach, L., Alegre, J., Poon, C., Agrela, F., & Cabrera, M. (2020). Crushing treatment on recycled aggregates to improve their mechanical behaviour for use in unbound road layers. *Construction and Building Materials, 263,* 120517. https://doi.org/10.1016/j.conbuildmat.2020.120517

[24] Dimitriou, G., Savva, P., & Petrou, M. F. (2018). Enhancing mechanical and durability properties of recycled aggregate

http://www.doi.org/10.62341/maec2810

concrete. *Construction and Building Materials*, *158*, 228–235. https://doi.org/10.1016/j.conbuildmat.2017.09.137

[25] Russo, N., & Lollini, F. (2022). Effect of carbonated recycled coarse aggregates on the mechanical and durability properties of concrete. *Journal of Building Engineering*, *51*, 104290. https://doi.org/10.1016/j.jobe.2022.104290

[26] Monkman, S., & Shao, Y. (2010). Integration of carbon sequestration into curing process of precast concrete. *Canadian Journal of Civil Engineering*, *37*(2), 302–310. https://doi.org/10.1139/L09-140

[27] Lu, C., Shi, C., Cao, Z., Guo, M., & Zheng, J. (2019). Effect of carbonated coarse recycled concrete aggregate on the properties and microstructure of recycled concrete. *Journal of Cleaner Production*, *233*, 421–428. https://doi.org/10.1016/j.jclepro.2019.05.350

[28] Xuan, D., & Poon, C. S. (2019). Sequestration of carbon dioxide by RCAs and enhancement of properties of RAC by accelerated carbonation. In J. de Brito & F. Agrela (Eds.), *New trends in eco-efficient and recycled concrete,* (pp477-497). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-102480-5.00016-6

[29] Pan, X., Zheng, W., Wu, H., & Wang, J. (2017). Improving the quality of recycled coarse aggregates through surface treatment: A review. *Construction and Building Materials*, *133*, 90–100. https://doi.org/10.1016/j.conbuildmat.2016.12.084

[30] Gholizadeh-Vayghan, A., Rajabipour, F., & Radlińska, A. (2020). Carbonation of recycled concrete aggregates: A systematic review. *Construction and Building Materials*, *246*, 118430. https://doi.org/10.1016/j.conbuildmat.2020.118430

[31] Junior, G. A. F., Leite, J. C. T., Mendez, G. de P., Haddad, A. N., Silva, J. A. F., & da Costa, B. B. F. (2025). A review of the characteristics of recycled aggregates and the mechanical properties of concrete produced by replacing natural coarse aggregates with recycled ones: Fostering resilient and sustainable infrastructures. *Infrastructures*, *10*(8), 213. https://doi.org/10.3390/infrastructures10080213

[32] Fellah, D., Barboura, S., Tilmatine, T., Benyahi, K., Kachi, M. S., Li, J., & Bouafia, Y. (2024). Compressive study on recycled concrete: Experiment and numerical homogenization modelling. *Frattura ed Integrità Strutturale*, *67*, 58–79.